National Aeronautics and
Space Administration

ESMD DV 001
EFFECTIVE DATE: 1/12/05

Exploration Systems Mission Directorate
NASA Headquarters
300 E Streets SW
Washington, D.C.

Exploration Systems Mission Directorate

Work Breakdown Structure

This WBS will evolve over the life cycle of Exploration Systems. This version establishes the framework for more detailed versions that will include the contractor WBSs that will be established as contracts are awarded. No architecture solutions have been selected and this WBS is intended to have the flexibility to accommodate any architecture selected. Any exceptions identified will be corrected and changed in future releases.

CHECK THE MASTER LIST-
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Révision	Effective Date	Description
Draft		4/28/04	Definition Phase Draft Release
Draft		6/21/04	BAA Baseline Release
Draft	Revision 1	8/25/04	Structure and Content modification to align with new directorate scope.
Draft	Revision 2	8/31/04	Document Format Change. Incorporation of Technology Work Breakdown Structures.
Draft	Revision 3	9/09/04	Template dictionary is documented in appendices. Systems defined for spirals two and higher are deleted from this release.
Draft	Revision 4	9/15/04	Editorial updates and inputs to Hubble Repair Section.
Draft	Revision 5	9/20/04	Format modification. Appendix A content is moved to within the body of the document. Signature page updated.
Draft	Revision 6	9/22/04	Updated section 2.6 SBA breakdown
Baseline		12/10/04	ESMD PMC Board Approval

Office of Exploration Systems Mission Directorate
Work Breakdown Structure

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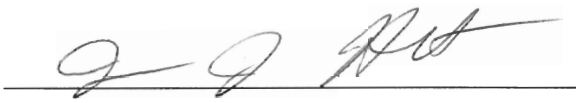

1/12/2005

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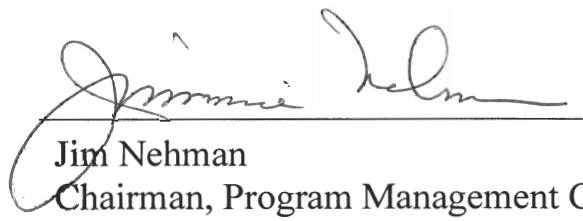

1/12/2005

Jim Nehman
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Date

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i Introduction to WBS Dictionary

i.i Goals and Objectives

The goals and objectives for the WBS are to provide a backbone framework for work management. The WBS structure supports management tools to assist in Earned Value Management (EVM), Requirements Flow-down, Risk Management, Integrated Product Team Definition, and Simulation Based Acquisition. It provides the back bone for EVM by establishing the structure by which schedule development and resource loading can occur. It eventually becomes aligned with the NASA UPN codes and supports development of the basis for Program Operating Plan Development.

Requirements flow down is supported by establishing "parent-child" relationships through a system hierarchical decomposition of the hardware elements. Risk Management is supported by providing a thorough assessment of all activities required to achieve the end item throughout the life cycle of its existence.

The structure's categorical alignment to system of systems products assist in clearly defining fundamental systems necessary to provide capabilities in order to achieve a defined mission. As future missions and associated systems to conduct those missions are defined, the WBS will be expanded to include those elements. It also provided for a framework in which simulation modeling and integration tools are developed.

i.ii System Hierarchy

The hierarchical description of the system provides a disciplined decomposition such that requirements flow. This WBS categorizes the system in a hierarchy description per the following levels of decomposition within the overall system architecture Per NASA SP-6105.

- Tier 1 Directorate Elements (Constellation System of System Capabilities)
- Tier 2 System (Crew Exploration Vehicle, Launch Vehicle Systems)
- Tier 3 Segment (Crew Module, Ground Segment)
- Tier 4 Element (Life Support, Stage (n), Facilities)
- Tier 5 Subsystem (Booster Main Engine, Booster MPS) (if required)
- Tier 6 Assembly (Thrust Chamber Assembly; turbo pump Assembly, etc.)(if required)

1.0 Directorate Management

This element encompasses all the work required to organize, plan, lead, and control the activities assigned to the Explorations Systems Mission Directorate (ESMD). Activities include establishing team norms, values, and leadership philosophies, as well as advocating within, and external to, the agency for resources to achieve ESMD goals.

Activities also include working with customers to set ESMD goals and communicating these goals to the Directorate.

This element shall provide the necessary Directorate controls to ensure proper oversight of directorate operations. This shall include business systems and analysis and performance measurement systems and analysis. Additionally, the resources necessary to manage the workforce and provide Performance Operating Plan (POP) inputs as required resides in this element.

The Directorate Management area shall also account for all work required to provide periodic reviews of the activities within the ESMD. This includes both internal reviews across the Directorate as well as external reviews of Directorate activities for adequacy and compliance.

1.1 Research and Policy Communications

TBD

2.0 Directorate and Division Systems Integration

This element provides the Directorate's overarching effort for systems engineering. It includes establishing and directing an integrated engineering effort throughout the Directorate. This effort includes, but is not limited to, identifying processes, methods and tools for engineering, including Simulation Based Acquisition (SBA); effort associated with the integration of ESMD activities with those of other Directorates; development of capabilities requirements required to meet operational objectives to be accomplished by Exploration Systems and the overall campaign for exploration of space based on Agency provided requirements and science objectives; development and implementation of the overall ESMD configuration management and risk management programs; and definition of applicable Systems Engineering and Systems Management standards and policies to be implemented. This element also includes the work to interface with other organizations, customers, suppliers, and regulatory agencies to define and evaluate technical accomplishments of project and program priorities. This work excludes the systems engineering effort that can be associated specifically with the lower tiers of the architecture in the contract end item or ground systems branches of the WBS.

2.0.1 Management and Administration

This element provides the work to set policy for the Directorate's overall systems engineering effort. It includes Directorate guidance for required reviews and associated plans, the Systems Engineering Management Plan (SEMP), systems engineering reports, supportability strategy, program/project requirements documents, and system description documents. This element provides stakeholder representation in all phases of the System of Systems (SS) life cycle. It includes the work associated with reduction in total ownership cost planning. Further scope includes the identification of applicable Standards and Specifications for ESMD programs and projects; the coordination of concurrent engineering across the ESMD tier one elements where appropriate; management of the technical effort to assess cost and risk over a broad range of exploration architectural options; and the strategic planning for technical workforce and

facility needs over the next few decades. This work establishes the systems engineering strategy needed to ensure product development and integration across the directorates, as well as documentation products, including: a Work Breakdown Structure (WBS), SEMP, project review plan templates, review agenda templates, and review reports templates.

2.0.2 Configuration Management

This element captures the efforts for managing the Directorate configuration items for all Directorate-level documentation including the campaign, mission apability/programmatic requirements. This element establishes policy and standards for all ESMD Configuration Management activities. Documentation products include, but are not limited to, an ESMD Configuration Management Plan and a Configuration Management Plan template for ESMD programs and projects.

2.0.3 Risk Management

This element will implement risk management at the Directorate level and coordinate risk management for the SS and their constituent projects that comprise Exploration. This element includes the overarching coordination of the identification, analysis, planning, tracking, and control for Directorate-level risk reduction. These processes shall be applied to the technical, schedule, and cost aspects of the Directorate. This element includes oversight and insight in the planning and conducting of project/demonstrations and trade analysis to reduce the risk of the overall program. The overall ESMD risk management policy shall be established in this element. This shall include the preparation for baselining of a risk management plan documenting the implementation approach to risk management at the Directorate level, as well as risk management policy at the SS level and below. Risk management plans for the constituent SS will be monitored for compliance with Directorate-level risk management policy. Documentation products include, but are not limited to, a Risk Management Plan and a Risk Management Plan template for ESMD programs and projects.

2.0.4 Space Logistics

This element encompasses all the work required - to develop strategy and direct Directorate campaign and mission ground and space supportability engineering and integrated logistics support efforts - to provide mission sustainability. Efforts include supportability analyses and integrated logistics support management and engineering concepts and techniques that are integral to System Integration and Test of support infrastructures. This element identifies supportability factors for mission risk and life cycle cost that include sustainability, interoperability, obsolescence, and standardization. Strategy development includes total life cycle system management (TLCSM) and performance based logistics (PBL) sustainability concepts**.** Work includes oversight and insight for efforts to minimize the logistics footprint and reduce life cycle cost. This element coordinates closely with the reliability and maintainability disciplines to provide more effective, affordable, operationally-ready systems through increased Reliability and Maintainability.

2.1 Reserved

2.2 Exploration Systems Mission Directorate Integration

This element encompasses all the effort required to establish Directorate policy, planning and collaborative processes to enable integration with other NASA Directorates and HQ codes, and within the ESMD elements. This element includes coordination with external agencies such as the Department of Defense (DoD), the Department of Energy (DOE), Environmental Protection Agency (EPA) and the Federal Aviation Administration (FAA). Activity includes policy for security, environmental protection, planetary protection, external relations, procurement, legal, human resources, Equal Employment Opportunity Commission (EEOC), legislative affairs, and public affairs. This element encompasses all the effort required to develop an internal review plan and support external reviews as required. Documentation associated with this work includes integrated agency capability and technology traceability assessment showing linkages from development activities to the Space Architect's space strategy.

2.3 Reserved

2.4 Acquisition and Management Systems Division Integration

2.5 Reserved

2.6 Development Programs Division Integration

2.7 Reserved

2.8 Requirements Division Integration

2.9 Reserved

2.10 Requirements Definition

Effort includes the identification of Exploration stakeholders and capture of stakeholder needs and desires through elicitation of needs, wants, expectations, constraints, and goals. Activity includes design of mission scenarios with supporting trade studies and analysis based on constraints/resultant requirements from stakeholder definition activity. Scope includes the effort for planning specific missions required to meet exploration goals, including definition of all required precursor missions to support human exploration missions, and associated operations concepts. This effort establishes top level decision analysis criteria and mission needs statements. Trade studies are implemented to determine optimum combination of mission objectives. Analyses include fundamental feasibility studies for initial probes into Systems Options/ Supportability Assessments/Cost Assessments/Initial Risk (Technology Assessments) for various operational /functional/physical architectures based on the integration of science objectives with exploration systems requirements. Also includes the development of human health and performance criteria in order to affect design of human-rated spacecraft and mission design.

Top-level SS-level requirements are generated and programmatic requirements are identified (relevant effectiveness, risk, cost, schedule, institutional/national/international constraints, mission classifications) and documented. Scope includes the periodic assessment of campaign and mission definitions/mission needs based on progress of associated capabilities, operational considerations, and/or adjustment in stakeholder needs. Scope includes the identification/validation of robotic program objectives to acquire the environmental data and demonstrate key technologies to inform mission and system designers. Scope also includes the guidance for the identification of the balanced level of commonality between robotic and human propulsion and between propulsion and surface power for Nuclear Investment Strategy.

Documentation products include mission needs expressed as SS operational/capability requirements, in a ESMD-RQ-0021 document, to include thresholds/objectives for cost, schedule, and performance and a Concept of Operations document. Deliverables will also include results from trade studies and associated support data. Study package includes a proposed top-level integrated architecture with initial straw man strategic architectures laid out for analysis, a notional schedule that highlights needed capabilities along in the form of timelines for required capabilities along with the identification of near-term decisions and forward work, and the major critical trades identified for detailed drill down studies.

2.10.1 Systems Integration

TBD

2.10.2 Requirements Formulation

TBD

2.10.3 Exploration Analyses

TBD

2.10.4 Operations Advisory Group Activity

TBD

2.11 Simulation Based Acquisition

This element will: provide modeling and simulation (M&S) capabilities that support the life-cycle of a system through acquisition to disposal; identify, modify and/or development analysis tools, models and simulations that support assessment of system performance, cost and risk; provide integration of the M&S capabilities with system definition data and deploy through the ESMD Integrated Collaborative Environment (ICE); and create M&S interfaces and development plans with the ESMD development contractors.

2.11.1 SBA Management

This element provides overall planning, management, and oversight of SBA definition, development, and deployment activities.

2.11.1.1 Planning and Management

This element will provide for the creation and management of the SBA long-term development roadmaps; development and maintenance of all SBA status reports internal and external to ESMD; identification of necessary SBA resources (e.g., personnel and budget); and management of personnel.

2.11.1.2 Budget and Schedule Planning

This element will provide for the development and management of the SBA budget and schedule.

2.11.2 SBA Systems Engineering

This element will provide for: identification and validation of user/stakeholder requirements; ensuring the system design and production satisfies user/stakeholder requirements (verification) and meets their needs (validation); and definition and management of the necessary processes and controls to ensure objective(s) is met.

2.11.2.1 Requirements Analysis

TBA

2.11.2.2 Functional Analysis and Allocation

TBA

2.11.2.3 Synthesis

TBA

2.11.2.4 Analysis and Control

TBA

2.11.3 SBA Acquisition RFP Support

This element will: provide model-based contracting (e.g., integrated modeling and simulation) inputs to ESMD RFP development; identify, modify and/or develop models that will be used in the contracting process; provide modeling and simulation interface between government and contractors; and define evolutionary plans for embedding modeling and simulation into the ESMD acquisition process.

2.11.3.1 RFP Development

This element will: provide model-based contracting (e.g., integrated modeling and simulation) inputs to ESMD RFP development activities; identify, modify and/or develop models that will be used in the contracting process.

2.11.3.2 RFP Evaluation Support

This element will provide M&S support to the evaluation process following the receipt of contractor's proposals.

2.11.3.3 H&RT Interface/Support

This element will provide input to H&RT concerning model-based contracting needs.

2.11.3.4 Government/Contractor Interaction

This element will provide M&S interface between government and contractors.

2.11.3.5 Legal/Procurement evaluation

This element will provide a review and vetting of the process with both the lawyers and the procurement specialists.

2.11.4 SBA Development

This element will develop, deploy, and support SBA capabilities, including: 1) data model; 2) analysis, M&S capabilities; and 3) integration of the SBA elements.

2.11.4.1 Data Model

This element will develop the data model, referred to as the NASA Exploration Information Ontology Model (NExIOM) that captures, describes, and persists decision support information regarding Project Constellation architectures and technologies. The NExIOM will encompass architectures that span in maturity from conceptual to operational. NExIOM content will serve as the sole expression of Constellation architecture and technology data for the purposes of proposal submission, engineering analysis, modeling, simulation, assessment, reporting and decision-making. The NExIOM will be accessible to NASA for the purposes of retrieval, evaluation, analysis and review of Constellation data. The NExIOM will be accessible to industry for the purposes of submission and retrieval of Constellation data.

2.11.4.1.1 Scope Definition

The Scope Definition element will: result in defined boundary definitions (e.g., how much and what types of ESMD data are to be captured) for the NExIOM; and provide scope extension to a level appropriate to support ESMD decision making while not levying infeasible requirements on the analyst community. The data boundaries will govern the level of hardware sub-system data, granularity of performance data, and expansion of requirements data and breadth of architecture data encompassed by the NExIOM. In short, this task will determine the breadth and depth of the engineering, performance, and programmatic data that the NExIOM will capture.

2.11.4.1.2 Implementation

The Implementation elements will instantiate the NExIOM in the ESMD Integrated Collaborative Environment (ICE) system. The ICE will host the structural, descriptive, and relational schemas of the NExIOM as well as the instantiated data that conforms to them.

2.11.4.1.3 Definition

The NExIOM definition element will result in the specific descriptive and relational rules that will govern NExIOM data. These rules will be a result of the Scope task described above. NExIOM schemas govern the type, definition, and quantity of descriptive data for

each NExIOM data object. The types and quantity of relationships amongst these objects are also realized in the definition period.

2.11.4.1.4 Documentation

This element will develop documentation that describes the NExIOM data at levels appropriate for producing, editing, and viewing NExIOM data in support of ESMD decision-making activities. Detailed, understandable documentation enables contracting agreements to detail data delivery requirements that are NExIOM-valid.

2.11.4.1.5 Visualization and Manipulation

The visualization and manipulation element will produce mechanisms for exploring and manipulating NExIOM-valid OExS data. These mechanisms will provide the human portals into the NExIOM instantiation.

2.11.4.1.6 Brokering

Brokering development results in data transfer technologies between the NExIOM and other software systems. These systems include engineering analysis tools, simulation facilities, managerial applications, and reporting assets.

2.11.4.2 Analysis, Modeling, and Simulations

Working in partnership with the system and disciplinary analysts, this element will: ensure the availability of tools, models, and simulations necessary for a successful acquisition process; identify, modify (if available), or develop (if not available) tools, models, and simulations supporting traditional system/engineering performance, cost, and risk analysis; integrate tools, models, and simulations as appropriate, providing quantitative assessments of the system(s) figures-of-merit (FOM); provide ongoing support of the integrated analysis capabilities; modify, upgrade, and integrate the models and tools such that data can flow to/from the individual tools and data repository; and test and debug capabilities.

2.11.4.2.1 Cost Modeling/Analysis (DDTE, Prod, Ops)

Working in partnership with the cost analysts, this element will ensure the availability of credible and defensible cost assessment capabilities for future space systems; selection, development and/or modification of cost assessment tools and models that encompass the entire system life-cycle costs including: DDT&E, production, ground operations, flight operations, maintenance and disposal; provide continued support of this capability for the analyst community.

2.11.4.2.2 Risk Modeling/Analysis (Dev risk, Op risk, Safety)

Working in partnership with the risk analysts (e.g., safety and mission assurance (S&MA) personnel), this element will: ensure the availability of credible and defensible risk assessment capabilities for future space systems; ensure the selection, development, and/or modification of risk assessment tools and models that encompass the entire system risks including: flight or operations risk (e.g., safety analysis), and technology or architecture development risk that measures the likelihood that a given technology will

achieve a desired TRL by a given date; provide continued support of this capability for the analyst community.

2.11.4.2.3 Performance Modeling/Analysis

Working in partnership with the disciplinary analysts, this element will: ensure the availability of credible and defensible performance (e.g., flight mechanics, thermal, etc.) analyses of all aspects of architecture(s) as well as various technology impacts on architectures; ensure the selection, development and/or modification of physics-based disciplinary tools and models; test the interaction with other performance analysis tools; and provide general tool developer support once the tools are deployed.

2.11.4.2.4 Integrated Life-Cycle Modeling/Analysis (Ops,RMS, IVHM, Econ)

Working in partnership with the system analysts, this element will: ensure the availability of credible and defensible life-cycle (e.g., IVHM evaluation, operations discrete event analysis, reliability, maintainability and supportability assessment and economics assessment) analyses of all aspects of the architecture(s); ensure the selection, development, and/or modification of tools and models that address life-cycle related analysis not already covered in the cost and risk areas; and provide continued support of this capability for the analyst community.

2.11.4.2.5 Tool to Data Model Integration

This element will ensure that a common tool integration framework and methodology is used to "wrap" all the discipline tools for execution in the overall SBA engineering environment. The tools wrap is to be done using the data model that is being developed under another major SBA element. The individual wrapped tools shall be executable by any of the discipline expert analysts assigned to using the SBA process. The tool integration task is not only responsible for actually "wrapping" the various tools, but also for implementing the tool execution sequence, or process, desired by the analysts. The task is thus responsible for developing these processes and ensuring that they provide the needed FOMs for the technologies and architectures as their outputs. Finally, the task is also responsible for maintaining and supporting the tool wrappers as the execution of the SBA process proceeds.

2.11.4.2.6 Mission/Segment Simulators

This element will develop time-driven, event-sequenced simulation models of an architecture's mission segments (e.g., ascent, inter-planetary trajectory, or entry decent and landing). These segment simulators, which must be thought of as high fidelity performance and risk assessment capabilities, may not be needed immediately by SBA, but they will eventually become the backbone of the defensible detailed SBA performance and risk analysis. Initially, the simulators for each mission segment will incorporate low-fidelity discipline tools; however, in time, higher fidelity tools shall be incorporated by the task.

2.11.4.3 System Development and Integration

This element will: provide for integration of system components (e.g., data model, analysis models, simulations, etc.) into SBA capabilities; test and verify system against

plans and requirements; provide deployment of system and training of analysts; provide interface to ESMD CIO; and maintain awareness and provide direction on the use/application of standards in the development of SBA capabilities.

2.11.4.3.1 Design and documentation

TBA

2.11.4.3.2

2.11.4.3.3 Development

TBA

2.11.4.3.4 Integration

TBA

2.11.4.3.5 System administration

TBA

2.11.4.3.6 Test and verification

TBA

2.11.4.3.7 PDM deployment

TBA

2.11.4.3.8 System training and deployment

TBA

2.11.4.3.9 Data presentation

TBA

2.11.4.3.10 Standards

TBA

2.11.4.3.11 CIO Integration

TBA

3.0 Safety and Mission Assurance

The ESMD includes the technical and management efforts of developing and ensuring implementation of the policies unique to the Office of Exploration Systems, intended for the safety and mission assurance function in the disciplines of safety, environmental compliance (i.e., Environmental Protection Agency (EPA)), reliability, maintainability, supportability assurance, quality assurance, and operations. This venture includes an independent review and assurance function over the design, development, testing, supportability assurance, review, and verification of ESMD systems. It is to provide oversight of the S&MA Program Management functions with support to the

Program/System panels; review and approve ESMD S&MA policies, guidelines and plans; and conduct review and approval of S&MA deviations and waivers. This work excludes the safety and mission assurance effort that can be associated specifically with the lower tiers of the architecture in the contract end item or ground system braches of the WBS.

3.1 Management and Administration

This element will lead and manage the overall S&MA effort and provide the primary S&MA to other enterprise divisions. Includes support of necessary agreements (Annual Operating Agreement (AOA), Memorandum of Agreement (MOA)), resource plans (Program Operating Plan (POP)), and schedules. This effort provides sufficient review for certification of flight worthiness. Management and Administration will act as liaison between enterprises and the Chief S&MA Officer.

3.2 Project Assurance (Safety and Mission Assurance Integration)

This element includes the technical and management efforts necessary for establishing and integrating S&MA functions across all ESMD programs (Constellation, H&RT, and Prometheus) as required to complete the Exploration vision. Includes development of necessary plans, establishment of adequate safety, maintainability and reliability design requirements, and procedures to guide and direct the integrated safety and mission assurance functions through all phases of the initiative, from design through disposal. This element will ensure continuity across all lower level S&MA) functions. This element will support, as necessary, the review of contract Request for Proposals (RFP), Statements of Work (SOW), Data Requirement Deliverables (DRD), and Source Evaluation Boards (SEB), and will establish an Enterprise-level Risk Management Function.

3.2.1 Safety and Mission Assurance Panels

This element includes the technical support of ESMD S&MA Panels.

3.3 System Safety

This element includes the technical and management effort necessary to ensure the overall safety and protection of flight and ground personnel, general public, flight/ground hardware, software, and facilities through all phases of the initiative, including oversight/insight of contracted efforts.

3.4 Safety, Health and Environment Assurance (SHEA)

This element includes the efforts necessary to ensure that occupational (industrial) safety and health and environmental assurance functions for all aspects of the Exploration Enterprise are accomplished.

3.5 Reliability and Maintainability

This element includes the technical and management efforts necessary for assuring reliability, maintainability and for all aspects of the enterprise.

3.6 Product Assurance

This element includes the technical and management efforts necessary for assuring establishment, management, and maintenance of the overall quality system for system hardware and software across all ESMD programs. Ensure implementation of the product assurance requirements/plans for all aspects of the Enterprise. This element will assist in formulating an acquisition strategy that incorporates aspects of product assurance.

3.7 Software Assurance

This element includes the effort necessary to ensure that developed software meets overall S&MA requirements for the protection of flight and ground personnel, general public, flight/ground hardware, software, and facilities through all phases of the Enterprise. This element will ensure adequacy and implementation of software safety, reliability, and quality plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of flight/ground/surface software element and operations plans and range safety.

3.8 Operations Safety and Mission Assurance

This element includes the technical and management efforts necessary for assuring performance of flight/ground/planetary operations processes and procedures across ESMD programs. This element will ensure adequacy and implementation of operational procedures, flight rules, checklists, and guidelines. This element will ensure adequate policy for test, flight, ground, and mission operations (including transit and surface operations). Proper consideration of orbital debris generation and its potential affect and ensure proper planning for contingencies. This element will ensure proper range safety procedures and policies.

3.9 Human Rating and Crew Survival

This element provides for the effort to ensure the Program will certify human–rated space flight systems and to ensure the implementation of abort and escape, safe haven, emergency egress, and search and rescue for human space flight systems. The element also ensures that all human–rated flight systems are designed in compliance to agency Human-Rating Requirements for Space Flight Systems to preclude a catastrophic safety risk to the flight Crew**.**

This element will: establish human performance criteria and system usability requirements to ensure crew safety; verify space flight systems reliability and safety by test and analysis at the integrated system level during development, and prior to the first flight, with humans on board; and develop and implement a formal process to maintain the human-rating certification for the life of the Program.

3.10 Nuclear Safety

This element includes the effort necessary to ensure the overall safety and protection of flight and ground personnel, the general public, flight/ground hardware, software, and facilities across all ESMD programs when nuclear material is present. This element will include a nuclear risk management evaluation, and will ensure adequacy and

implementation of safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of nuclear hardware elements and operations plans and compliance with Federal law and regulations. This element also includes participation in the Inter-agency Nuclear Safety Review Panel (INSRP), and will implement policy prescribed in the National Environmental Protection Act.

4.0 Constellation Systems

i Introduction

The Constellation WBS is centered on a "System of Systems (SS)" focus. The structure is to achieve capabilities in which a mission can be formulated from the building block identified in this work. Each SS becomes integral to the total mission. The desire is to have capabilities that can be mixed and matched as missions and capability allow.

An approach for the WBS development is centered on formulating a functional template that can be replicated throughout the SS products to capture the work required throughout the products' life cycle(s). The template incorporates the lower-level decomposition based on the system hierarchical structure listed below. The intent is to provide consistency and discipline throughout. For example, if there are certain functions that are not performed for certain hardware elements, that number will be held in reserve. A desire to provide a disciplined format for ease of tracking and visibility was achieved by having a consistent numbering schema.

The structural template that was applied to this work breakdown is organized around fundamental cross-cutting functions to yield a capability (product). The upper-level functions such as management, systems engineering, and S&MA provide guidance and oversight of products. Since there is a collection of systems, mission objectives can be met by aggregating the appropriate capabilities necessary to meet the mission needs. It is important at the early stage of WBS development to maintain generic language until a time when functional decomposition can be completed.

ii Template

The template below is the generic example applied to the system hierarchy flow above.

- System Product
    - Systems Management
    - Systems Engineering
    - Safety and Mission Assurance
    - Technology Maturation (if required)
    - Integration and Test (Integration Function at the Higher Levels)
    - Operations
    - Product ground support systems
    - Next lower Tier of product 1
        - End Item Management Team
        - End Item RFP/SEB Support
        - End Item Integrated Product Team
        - End Item Prime Contract

- Systems Management
- Systems Engineering
- Safety and Mission Assurance
- Technology Maturation (if required)
- Integration and Test
- Operations
- Product ground support systems
- Next Tier of sub products

- Next lower Tier of product 2
- Next lower Tier of product (n)

This element encompasses all the work required to develop the necessary systems and conduct operations supporting human and robotic exploration missions to Earth orbit, the Moon, and beyond.

4.1 System of Systems I

Details of all elements in Sections 4.1.1 through 4.1.6 can be found in Appendix A of this document.

4.1.1 System Management

4.1.1.1 Progam/Project Management

See Appendix A

4.1.1.2 Business Management

See Appendix A.

4.1.1.3 Information Management

See Appendix A.

4.1.1.4 Administration

See Appendix A.

4.1.1.5 Requirements Management

See Appendix A.

4.1.1.6 Acquisition Management

See Appendix A.

4.1.1.7 Comprehensive Risk Management

See Appendix A.

4.1.1.8 Supportability and Integrated Logistics Support Management

See Appendix A.

4.1.2 System of Systems Engineering

See Appendix A

4.1.2.1 Engineering Management

See Appendix A.

4.1.2.2 Requirements Definition

See Appendix A.

4.1.2.3 Configuration and Data Management

See Appendix A.

4.1.2.4 Risk Identification and Analysis

See Appendix A.

4.1.2.5 System Definition

See Appendix A.

4.1.2.6 System Integration

See Appendix A.

4.1.2.7 Integrated Logistics Support

See Appendix A.

4.1.2.8 Integrated Discipline Team (IDT) Activity

See Appendix A.

4.1.2.8.1 Systems Engineering & Integration Team

See Appendix A.

4.1.2.8.2 Constellation Systems Analysis Team

See Appendix A.

4.1.2.8.3 Cost Engineering Team

See Appendix A.

4.1.2.8.4 Safety & Mission Assurance Team

See Appendix A.

4.1.2.8.5 Operations Team

See Appendix A.

4.1.2.8.6 Human Centered Engineering Team

See Appendix A.

4.1.2.8.7 Structural, Mechanical, Materials & Manufacturing

See Appendix A.

4.1.2.8.8 Command, Control & Communications

See Appendix A.

4.1.2.8.9 Ground Infrastructure

See Appendix A.

4.1.2.8.10 Aerosciences & Flight Mechanics

See Appendix A.

4.1.2.8.11 Propulsion & Fluids

See Appendix A.

4.1.2.8.12 Power Systems

See Appendix A.

4.1.2.8.13 Computer, Software, Automation

See Appendix A.

4.1.2.8.14 Robotics

See Appendix A.

4.1.3 Safety and Mission Assurance

4.1.3.1 Management and Administration

See Appendix A.

4.1.3.1.1 Business Management

See Appendix A.

4.1.3.2 Safety and Mission Assurance (S&MA) Integration

See Appendix A.

4.1.3.2.1 External Assessment

See Appendix A.

4.1.3.3 Safety and Mission Assurance Panels

See Appendix A.

4.1.3.3.1 RMS Review Panels

See Appendix A.

4.1.3.4 Safety, Health and Environment Assurance (SHEA)

See Appendix A.

4.1.3.4.1 Occupational (Industrial) Safety

See Appendix A.

4.1.3.4.2 Occupational Health

See Appendix A.

4.1.3.4.3 Environmental Protection

See Appendix A.

4.1.3.5 Reliability and Maintainability

See Appendix A.

4.1.3.5.1 Reliability

See Appendix A.

4.1.3.5.2 Maintainability

See Appendix A.

4.1.3.6 Product Assurance

See Appendix A.

4.1.3.6.1 Electrical, Electronic, Electromechanical (EEE)Parts

See Appendix A.

4.1.3.6.2 Materials and Processes Product Assurance

See Appendix A.

4.1.3.7 Software Assurance

See Appendix A.

4.1.3.8 Operations Safety and Mission Assurance (S&MA)

See Appendix A.

4.1.3.9 Human Rating and Crew Survival

See Appendix A.

4.1.3.10 Nuclear Safety

See Appendix A.

4.1.4 Advanced Development

This element provides for the integration of technology maturation needs and plans across the Constellation system of systems. This activity includes technical risk mitigation requirements and tasks identified in the risk management process and technology maturation tasks needed to support trade study decisions for system requirements and Design and Analysis solutions.

4.1.4.1 Research and Technology Integration

The work to identify Constellation requirements for technologies needing to be matured, as well as identifying the technologies themselves shall be performed out of this element. This includes assessments of the state-of-the-art for a given discipline as well as assessments of the capabilities required by specific components to meet requirements. These assessments can take the form of workshops, team endeavors, or contracted efforts. All efforts to communicate and report results of these assessments shall be performed out of this area as well.

4.1.4.2 Vehicle Subsystems

Advanced technology development for enhanced, power, actuation and health management subsystems, with concentration in the areas of electromechanical/electrohydrostatic actuators, long-life, lightweight PEM fuel cells power plant, non-toxic turbine power unit (TPU), and health management system architecture development.

4.1.4.2.1 Project Management (GRC)

Project management, including resource (budget, workforce, facilities) requirements/allocation/tracking, schedules, sub-project plans and documentation.

4.1.4.2.2 Actuators (Ends after FY04)

Advanced technology development in the areas of electromechanical and electrohydrostatic actuators.

4.1.4.2.3 Power

Advanced technology development in the areas of PEM fuel cells, batteries, turbine power units, ultracapacitors, and solid-state power controllers.

4.1.4.2.3.1 Power Technology Development (Lockheed Martin)

4.1.4.2.3.2 PEM Fuel Cell Powerplant (Teledyne Energy Systems)

4.1.4.2.4 Health Management Technology (Ends after FY04)

Advanced technology development in the areas of advanced system/subsystem diagnostics.

4.1.4.2.5 Avionics (Ends after FY04)

Advanced technology development in the areas of integrated advanced avionics LRU, high-speed data buses, and advanced embedded system software.

4.1.4.2.6 Mechanical Systems (Ends after FY04)

Advanced technology development in the areas of landing gear, tires and brakes.

4.1.4.3 University Institutes

The focus of the University Institutes Project is to provide Constellation with the products of long-term research and development. The institutes, at the time of this writing, had been devoted to specific research elements of high priority to the former sponsoring program, the Next Generation Launch Technology (NGLT) Program. However, the institutes currently are being refocused to better address the critical needs of Constellation. Specifically, the Project Team is working with the universities to define and pursue problems of interest in the following Transportation-focused areas: Thrust Chamber Assemblies, Propellant Storage and Delivery, Vehicle Thermal Structures, Design and Analysis Methods, Reentry Aerothermodynamics, Vehicle Subsystems, Systems Engineering and Integration and Education.

The overarching objectives of the University Institutes Project are to

1. Strengthen NASA's ties to academia through long-term, sustained investment in innovative and exploration technology critical to Constellation;
2. Enhance and broaden the capabilities of the nation's universities to meet the needs of NASA's science and technology programs;
3. Perform research and development that moves fundamental advances from scientific discovery to basic technology that addresses critical Constellation needs; and
4. Expand the nation's talent base for NASA mission-related research and development and technology maturation.

4.1.4.3.1 Project Management

The University Institutes Project is managed by the Glenn Research Center (GRC). As managing center, GRC will oversee research efforts, perform financial management and manage the peer review process for all Office of Exploration Systems fixed-price cooperative agreements with awarded universities that have migrated from NGLT.

The project organization encompasses three institutes which address problems of fundamental importance to Constellation. The three institutes all follow the same format of lead university and multiple supporting universities.

4.1.4.3.2 Institute for Future Space Transport

The Institute for Future Space Transport (IFST) is led by the University of Florida and includes the following supporting universities: Cornell University, Syracuse University, Georgia Institute of Technology, University of Alabama at Birmingham, Mississippi State University, North Carolina A&T University, and Prairie View A&M University.

The IFST is currently refining task plans that address issues in Thrust Chamber Assemblies, Propellant Storage and Delivery, Vehicle Thermal Structures, Design and Analysis Methods, Reentry Aerothermodynamics, Vehicle Subsystems, Systems Engineering and Integration, and Education.

4.1.4.3.3 Space Vehicle Technology Institute

The Space Vehicle Technology Institute (SVTI) is led by the University of Maryland and includes the following supporting universities: the University of Michigan, Johns Hopkins University/Applied Physics Lab, the University of Washington and North Carolina A&T University. The SVTI is currently refining task plans that address issues in Thrust Chamber Assemblies, Vehicle Thermal Structures, Reentry Aerothermodynamics, and Systems Engineering and Integration.

4.1.4.3.4 Rocket Engine Advancement Program 2

The Rocket Engine Advancement Program 2 (REAP 2) Institute is led by the University of Alabama at Huntsville and includes the following supporting universities: the Pennsylvania State University, Auburn University, Purdue University and Tuskegee University. The REAP 2 Institute is currently refining task plans that address issues in the Thrust Chamber Assemblies area.

4.1.4.4 Propulsion Technology & Integration Project

Includes all tasks necessary to support the objectives of the Propulsion Technology and Integration Project including: Develop and demonstrate key propulsion technologies to that can significantly enhance mission performance, safety, and cost savings for Reusable Launch Vehicles, In-Space Transportation Systems; develop alternate and supporting technology to address identified areas of high risk of the next generation main engine; address subsystem and component technology maturation for evolution and improvement of development and flight systems to extend reliability, safety and performance margins beyond those established at the demonstration/prototype levels

4.1.4.4.1 Project Management/Systems Engineering

The business, administrative and technical management effort of planning; organizing; directing; approving; and controlling activities to accomplish the project goals and objectives

4.1.4.4.1.1 Project Management and Administration

The Project Management and Administration includes the Overall Project Management and Quality Assurance Management.

4.1.4.4.1.2 Business Management

The Business Management includes the Overall Budget Management. This task is responsible for any Earned Value Assessments required by the project or program,

4.1.4.4.1.3 Systems Engineering and Integration Management

System Engineering and Integration Management directs all technical efforts for the tasks set up to meet the PTIP objectives. The Lead Systems engineer is responsible for coordination of technical requirements and verification from the program down to each task. The LSE also has primary responsibility for Risk Management.

4.1.4.4.1.4 Schedule Management

Schedule Management is responsible for the tracking of project progress of all defined tasks and subtasks. Schedule Management provides support to the Business Management in any Earned Value Assessments required by the project or program.

4.1.4.4.1.5 Configuration Management & Document Control

Includes implementation of a systematic approach for identification of project information and data requirements.

4.1.4.4.2 Advanced Materials

This element will include all Advanced Materials Technology tasks approved by the program in support of the NGLT and PTIP goals and objectives.

4.1.4.4.2.1 GRCop-84 Materials and Processes Development

This element will include all the activities necessary to satisfy the Technical Description and Objectives described in the following paragraph.

All RLV engines require actively cooled structures either for combustion chambers (SSME derived, full flow staged combustion, aerospike) or for nozzle ramps (aerospike). Past work, primarily from NRA 8-21, has shown the significance of the life and performance benefits of GRCop-84 over today's alloys such as NARloy-Z. GRCop-84 has been taken to TRL 5 for small thrust cells, but larger scale components are not as mature. Optimally these large heat exchangers should be made from thin sheet to minimize manufacturing cost and time required for production. No such technology exists today, but prior laboratory scale work has shown the feasibility of making 0.003`` - 0.040`` thick sheet from GRCop-84. Extending the capability to producing large sheet and structures is a low risk means of making metallic actively cooled structures for all engines under consideration for 2nd and 3rd Generation RLV vehicles.

4.1.4.4.3 Tools and Diagnostics

This element will include all Tools and Diagnostics Technology tasks approved by the program in support of the NGLT and PTIP goals and objectives.

4.1.4.4.4 Miniaturized Leak Detection

This element will include all the activities necessary to satisfy the Technical Description and Objectives described in the following paragraph.

An integrated smart leak detection system for a range Next Generation RLV propulsion systems will be demonstrated. A microsensor array, which includes hydrogen, oxygen, and hydrocarbon sensors will be produced by MEMS-based technology. The array will be incorporated with signal conditioning electronics, power, data storage, and telemetry.

This final system will be self-contained with the surface area of a postage stamp. This project feeds into a separate KSC led proposal "Leak Detection Testbed" being submitted to Next Generation Operations Project and builds from technology development in the Bantam program. This system is intended to enable Gen II vehicle to use a large numbers of gas sensors to determine system condition and enable rapid turn-around required for cost-effective operation. This task significantly affects the safety and cost objectives of the next generation of launch vehicles: the ability to quickly and reliable detect and locate hydrogen leaks have repeatedly been demonstrated to be a significant safety and cost problem on the Shuttle. This task will develop a stand-alone system to detect both hydrogen with the corresponding amount oxygen as well as hydrocarbon fuel leaks and is thus applicable to a wide range of possible Gen II vehicle designs. GRC lead; KSC, Case Western Reserve University, Makel Engineering, Inc. partners.

4.1.4.4.5 Combustion Devices Injector Technologies (CDIT)

This element will include all the activities necessary to satisfy the Technical Description and Objectives described in the following paragraph

Provide risk mitigation for NGLT propulsion projects. Use CFD as an injector and combustion devices design tool. Improve Turn around - impact the design during the design cycle. Improve Accuracy - designers confidence of solution accuracy. Validated tools and database made available to combustion devices community. Enhance experience / skill base necessary for effective insight. Evaluation of designs to meet NGLT goals. Capability to accurately and efficiently model a range of injectors designs. Leverage experience and skills of national experts: PSU for single element scale testing; UAB, UF, Purdue, and MSFC for design & analysis tools development.

4.1.4.4.6 Propulsion High Impact Avionics Technologies (PHIAT)

This element is a technology development task concentrating on advanced avionics technologies. The purpose of the Propulsion High Impact Technology Project (PHIAT) is to develop Avionics Technologies that will increase reliability and safety of propulsion and avionics systems, decrease development, sustaining engineering, and operations cost of propulsion and avionics systems, and decrease overall avionics system and propulsion system weight. Hardware being developed, integrated and demonstrated under this task includes: 1) a distributed, digital data bus, 2) intelligent pressure and temperature sensors with multiple elements, 3) smart actuator and controller power switch, 4) oxygen safe, low intrusion, flow meter and 5) integrating GRCs miniaturized leak detection sensor (MLDS).

4.1.4.5 Integrated Power Head Demonstration

4.1.4.5.1 Integrated Project Management

4.1.4.5.1.1 Air Force Research Lab Joint Management Activities

This main work element is the activity that the Air Force Research Laboratory (AFRL) Engine Systems Branch performs as the overall government management organization of the project. This includes overall project control including contract management for the government, coordination with MSFC, coordination with prime contractors, and

coordination with DOD funding source -Integrated High Payoff Rocket Propulsion Technology Program (IHPRTP). Additionally, this element includes technical review, in support of IPD, by AFRL Engine Systems Branch personnel and other DOD organizations.

4.1.4.5.1.2 MSFC Joint Management Activities

This work element includes the coordination activity performed at MSFC to assist AFRL in the overall project management and insight into the business activities of the IPD Prime contractors. These activities include the coordination of overall cost analyses, coordination and review of proposed contract modifications, control of project level action items, control of integrated schedule, control of project level risk management and associated risk tracking system, and additional tasks.

4.1.4.5.2 Aerojet Activities

4.1.4.5.2.1 Project Management

This work element includes all the management conducted by GenCorp Aerojet on the IPD Contract F04611-94-C-0035 between AFRL and Aerojet. This activity includes all activities of the Aerojet Project Manager, the Aerojet business office (including contract management, schedule management, cost reporting, etc), the Aerojet Chief Engineer for the IPD project, and the systems engineering activities required to support coordination with SSC and Rocketdyne for utilization of the Aerojet components in the IPD Engine systems activities.

4.1.4.5.2.2 Nozzle Design and Fabrication

This work element includes all activity to design, analyze, fabricate, and verify integrity of the IPD channel wall nozzle. This activity includes conceptual, preliminary, and critical design reviews, as well as development of the component report. All process verification activities needed to validate the fabrication process used in making the channel wall nozzle are included this element. All fixtures needed to move, handle, and process the part are included in this work element as well.

4.1.4.5.2.3 Oxygen Preburner

This work element includes all activity to design, analyze, fabricate, and verify integrity of the IPD Oxidizer Rich Preburner. This activity includes conceptual, preliminary, and critical design reviews, as well as development of the component report. All process verification activities needed to validate the fabrication process used in making the Oxidizer Rich Preburner are included in this element. Additionally, this element covers the component design personnel's participation in the Oxidizer Rich Preburner's test activity in WBS 2.4.2.6 and all fixtures needed to move, handle, and process the part.

4.1.4.5.2.4 Hydrogen Preburner

This work element includes all activity to design, analyze, fabricate, and verify integrity of the IPD Hydrogen Rich Preburner. This activity includes conceptual, preliminary, and critical design reviews, as well as development of the component report. All process

verification activities needed to validate the fabrication process used in making the Hydrogen Rich Preburner are included this element. Additionally, this element covers the component design personnel's participation in the Hydrogen Rich Preburner's test activity in WBS 2.4.2.6 and all fixtures needed to move, handle, and process the part.

4.1.4.5.2.5 Preburner Testing @ Aerojet

This element covers all test personnel activities at the E6 Test facility at Aerojet while component testing both the Oxidizer Rich and Hydrogen Rich Preburner. Activities include stand modification to prepare for either preburner, activation testing to demonstrate facility readiness to test, and actual testing of the preburners. Additionally, this element includes all participation of all reviews from the test organization including, but not limited to the Critical Experiment Review, Test Readiness Review, and Post test Data Reviews.

4.1.4.5.2.6 Replan and Proposal

This element is utilized to develop detailed proposals when needed to modify the contract.

4.1.4.5.3 Rocketdyne Propulsion and Power Activities

4.1.4.5.3.1 Engine Systems Development

The Engine Systems Development includes all the activities related to the design, fabrication, assembly, and test related activities at Boeing Rocketdyne. This element includes the systems engineering activities and coordination with SSC and Aerojet needed to integrate the components into an engine system and successfully test at SSC. The major components found in the element are the engine controller, the ancillary systems, the propellant ducts, and the valves. Ancillary lines are also designed and fabricated under this element. The systems engineering aspect of this element includes the development of the Interface Control Document, the Inter-Engine Interface Control Document, the Power balance iterations, the transient model development, and all other engine level control documentation. The Systems Requirements Review, Engine Preliminary Design Review, and Engine Critical Design Review are the major Review activities in this element, although reviews of some of the subsystems are also included.

4.1.4.5.3.2 Management

The Management element of the Boeing work structure covers all activity performed in the project management and business management of the IPD project at Boeing Rocketdyne. This element does not include IPT management leads that are held within the component level work activities.

4.1.4.5.3.3 Data

This element covers all Information Technology activities occurring at Boeing Rocketdyne to accomplish the other elements of the IPD Project. This includes the support for the Nexprise system, the Boeing Risk Control system, and Boeing Action Control system being utilized by IPD.

4.1.4.5.3.4 Oxygen Turbopump

This work element includes all activities in the design, fabrication, assembly, and component test support of the IPD Liquid Oxygen turbopump. The activity includes all Boeing support for component tests of the pump including the gaseous nitrogen blowdown tests, the hot fire turbopump tests, and the oxygen preburner checkout testing required to accomplish the hot fire testing. Support of SSC test facility activation testing related to the hydrogen turbopump test is included in this element. All disassembly activity and disassembly reports also occur under this activity.

4.1.4.5.3.5 Liquid Hydrogen Turbopump

This work element includes all activities in the design, fabrication, assembly, and component test support of the IPD Liquid Hydrogen turbopump from Boeing. The component testing is limited to gaseous hydrogen turbine blowdown testing of the hydrogen turbopump. Support of SSC test facility activation testing related to the hydrogen turbopump test is included in this element. Any disassembly activity and disassembly reports also occur under this activity.

4.1.4.5.3.6 Main Injector

This work element involves the design and fabrication of the gas-gas main injector and the powerhead assembly. All fabrication process verification experiments, associated NDE, and proof tests are included in this activity.

4.1.4.5.4 Stennis Space Center Activities

4.1.4.5.4.1 Oxygen Powerpack Testing

This element contains the activities performed by SSC to design, fabricate, install, analyze, and operate the E1 Cell 3 test facility at SSC for the Liquid Oxygen component tests. The test activities include gaseous nitrogen blowdown tests and hot fire component tests of the IPD Liquid Oxygen Turbopump. In addition, the Workhorse preburner only testing, used to characterize the Workhorse preburner prior to use in the Liquid Oxygen Powerpack tests, are performed under this element.

4.1.4.5.4.2 Hydrogen Powerpack Testing

This element contains the activities performed by SSC to design, fabricate, install, and operate the E1 Cell 2 Test facility at SSC for the testing of the IPD Hydrogen Turbopump. The activity has been descoped to include only gaseous hydrogen turbine blowdown tesing of the turbopump and no longer includes testing of the fuel preburner or hydrogen powerpack.

4.1.4.5.4.3 Engine Systems Testing

This element contains the activities performed by SSC to design, fabricate, install, and operate the E1 Cell 3 Test facility at SSC for the testing of the IPD Demonstrator Engine System. This element includes all SSC coordination activities between SSC and either Rocketdyne, Aerojet, AFRL, or MSFC. All SSC systems engineering activities for the Engine tests are included in this work element.

4.1.4.5.5 Marshall Space Flight Center Activities

4.1.4.5.5.1 MSFC Specific Project Management Activities

This work element includes all the IPD Project Management Activities at MSFC that are performed as a result of MSFC procedures, which do not relate to AFRL or the contractors. This activity includes development of the CWC requirements and subsequent negotiations, reporting activities to the NGLT Program and NGLT Projects office, activities related to MSFC ISO 9000 compliance, activities related to property management of the GSFC controlled E6 test facility, etc…

4.1.4.5.5.2 Technical Insight

This work element is the primary function of MSFC personnel on this Project. The intent of this element is to properly follow the activities of the prime contractors and SSC and provide expert opinion to the organizations performing the activity and the IPD Project. The areas where MSFC personnel provide insight include but are not limited to: test activities, component design, fabrication, problem resolution, hardware observations, data reviews, and system engineering.

4.1.4.5.5.3 Special Studies

This element involves special activities where independent analysis or testing is performed by MSFC personnel at the MSFC Project Manager's request to assist in resolving difficult technical issues facing the IPD Project. This activity is directed at independent work that directly addresses an area of high risk for the project.

4.1.4.6 Auxiliary Propulsion

The auxiliary propulsion system element provides auxiliary propulsion system technology development deemed relevant to NASA's Exploration Initiative. The auxiliary propulsion system element is composed of all propulsion hardware for reaction control systems (RCS), integrated auxiliary propulsion system (APS) test bed, cryogenic fluid management systems development, orbital maneuvering systems (OMS), and upper stage engine development, though not all are active. The auxiliary propulsion system element will provide technology development efforts leading to a risk reduction phase, which will significantly reduce the risk to full-scale vehicle development for the Exploration Transportation System. Risk reduction will be accomplished through analysis, design, and test demonstrations at the part, component, subsystem, and system level. No actual work is planned or performed against this WBS element; all effort is allocated to and charged against the lower level elements described below.

4.1.4.6.1 Project Management and Systems Engineering

4.1.4.6.1.1 Project Management and Systems Engineering

This task includes all the work force and resources required to manage budget, schedule, scope, configuration, data, in-house support, and risks associated with the Auxiliary Propulsion Project. It includes coordination and implementation of Project boards to accomplish data management and configuration management.

4.1.4.6.1.2 General Propulsion Insight (GRC)

Support from the Glenn Research Center directed towards technical insight of propulsion activities within the Auxiliary Propulsion Project.

4.1.4.6.2 Reserved

4.1.4.6.3 Reaction Control Engine 2 Development

4.1.4.6.3.1 Aerojet Reaction Control Engine Development, Management and Insight

This task includes the work force and resources necessary to ensure Level 2/3 insight into the development of three non-toxic LOX/Ethanol reaction control thrusters by Aerojet, including the design and test associated with the development of the workhouse and prototype thrusters. This effort includes the evaluation of deliverable data including plans, designs, analyses, and test results; coordination of and participation in weekly teleconferences, technical interchange meetings, test readiness reviews, and design reviews at both Government and contractor facilities; identification and tracking of risks associated with the Aerojet contracted effort; independent analysis and investigation of high-risk issues; support of Project and Program status meetings and milestone reviews.

4.1.4.6.3.2 Contracted Task -- Aerojet -- LOX/Ethanol Reaction Control Engine

This task includes the contracted effort with Aerojet for the development, design, test, and delivery of 3 LOX/Ethanol reaction control engines.

4.1.4.6.4 Integrated Auxiliary Propulsion System Test Bed

4.1.4.6.4.1 Integrated Auxiliary Propulsion System Test Bed, Management and Insight

This task includes the work force and resources necessary to oversee and coordinate the development of a flight auxiliary propulsion system simulator (minus engines) at the White Sands Test Facility (WSTF). The effort includes design, fabrication, and acceptance of the APS simulator and integration and test Aerojet prototype thrusters provided under separate elements of this WBS.

4.1.4.6.4.2 Auxiliary Propulsion System Analysis and Evaluation (MSFC)

The analyses performed by the Marshall Space Flight Center in support of the APS development.

4.1.4.6.4.3 Auxiliary Propulsion System Level Test (JSC/WSTF)

This task includes the manpower and resources necessary to perform system-level thruster testing at the White Sands Test Facility (WSTF) of the three prototype engines developed by Aerojet, including buildup and checkout of the test facilities, development of test requirements and test procedures, performance of the test procedures, and reduction of test data. In support of these activities, dynamic analyses of the test stand will be performed at WSTF and cryogenic feed system testing will be performed at JSC. This effort includes all of the activities necessary to conduct a successful test program,

such as technical interchange meetings, requirements and design reviews, test readiness reviews.

4.1.4.6.5 Hydrogen Peroxide Component Development

4.1.4.6.5.1 Hydrogen Peroxide Component Development, Management and Insight

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan,

4.1.4.6.5.2 Contracted Task -- Boeing -- Turbopump, Gas Generator, and Igniter Development and Test

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan.

4.1.4.6.5.3 Contracted Task -- Boeing Rocketdyne -- Chamber Material and Injector Development

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan.

4.1.4.6.5.4 Injector Testing at SSC

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan.

4.1.4.6.5.5 Contracted Task -- General Kinetics -- Catalyst Sensitivity Testing

This task was completed and closed out under the 2nd Generation RLV Program and is no longer active.

4.1.4.6.5.6 Contracted Task -- Moog -- Integrated Fluid Gas Controller Development

This task was completed and closed out under the 2nd Generation RLV Program and is no longer active.

4.1.4.6.5.7 Contracted Task -- P&W/Aerojet -- Detonation Test

This task was completed and closed out under the 2nd Generation RLV Program and is no longer active.

4.1.4.6.5.8 Contracted Task -- Purdue – Vac Characterization and Vac Decomp w/ Hypergolic Blend (Grant)

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan.

4.1.4.6.5.9 Contracted Task -- Purdue -- Propellant Management Device Demo (Grant)

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan.

4.1.4.6.5.10 NASA Led Task -- H2O2 Optimization Study (TD40/ED36). Single Element Injector Hot Fire

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan.

4.1.4.6.5.11 Contracted Task -- Orbital Sciences Corporation – Peroxide Enrichment Skid Activation (SSC)

This task has been concluded under the project control of 2GRLV-ONORB-PLAN-003, On-Orbit Propulsion Systems Project Plan.

4.1.4.6.5.12 NASA Led Task -- Hybrid Sounding Rocket Test (GSFC)

This task was concluded with the successful launch of the Hybrid Sounding Rocket in December 2002 and is no longer active.

4.1.4.6.6 Cryogenic Fluid Management Systems Development

4.1.4.6.6.1 Cryogenic Fluid Management Systems Development, Management and Insight

This task includes the work force and resources necessary to manage and oversee all CFM systems development work within the project. This effort includes the evaluation of deliverable data including plans, designs, analyses, and test results; coordination of and participation in weekly teleconferences, technical interchange meetings, test readiness reviews, and design reviews at both Government and contractor facilities; identification and tracking of risks associated with the contracted effort; independent analysis and investigation of high-risk issues; support of Project and Program status meetings and milestone reviews.

4.1.4.7 Orbital Express

The Work Breakdown Structure (WBS) Dictionary defines the elements that describe the work effort planned for the Orbital Express (OE) support tasks. The WBS and Dictionary cover the tasks identified in FY05 through FY07. This structure provides the basis for successful management of the MSFC tasks in the areas of planning and budgeting, software engineering and testing, interface management with Boeing and DARPA, and risk reduction.

This element covers the overall Orbital Express (OE) Flight Demonstration Program. This encompasses activities required for the development of autonomous rendezvous and control sensors in support of an on-orbit satellite servicing infrastructure for routine, cost-effective, autonomous capability for re-supply and reconfiguration of on-orbit space-craft in the post-2010 timeframe.

4.1.4.7.1 Project Management

This element encompasses the Project Management activities required to accomplish the Project objectives; ensure that the technical tasks are carried out; policies and procedures are adhered to; coordinate activities associated with budget analysis and allocation, system workforce utilization, and integrated project schedules are maintained; develop communication and reporting statuses; and respond to unexpected requests for

information. This element also includes the effort required to support OE design reviews, and Test Readiness Reviews. Additionally, this element encompasses the effort required to prioritize technical and programmatic risks. Work includes approval and funding of risk mitigation plans, tracking of mitigation progress and status reporting to system stakeholders.

4.1.4.7.1.1 AVGS SW Configuration and Data Management

This element develops project configuration and data management plans for managing the overall configuration of the AVGS flight software throughout the development and implementation phases. Scope involves the planning, organization, integration, support, and monitoring functions for tracking changes, conducting project control board reviews, and maintaining configuration documentation to include decision support data. This element includes management of document configuration and follows MSFC policy and standards.

4.1.4.7.2 Systems Engineering

This element includes the implementation of processes necessary to separate elements of the system into manageable work elements and allow those elements to be readily integrated into the final product that meets its intended capability. These processes include AVGS Software requirements definition, decomposition and prioritization, and risk assessment. The requirements include both technical requirements along with funding and schedule needed to enable these technical requirements. The effort also includes decomposition of requirements to technologies that must be matured prior to system acquisition.

4.1.4.7.2.1 AVGS System Definition

This element oversees the design of the AVGS Software and ensures that hardware and software interfaces are maintained between physical products and functional processes. This element monitors lower tier AVGS Software design activities and guides the implementation of procedures necessary to concurrently develop products and their associated processes. Work includes participation in lower tier design reviews to ensure the product design and associated manufacturing, test, and support processes meet the intended need. System analyses include operational feasibility studies, effectiveness analyses, environmental assessments, technology assessments, hardware and software feasibility assessments based on design models and resultant overall systems risk identification.

4.1.4.7.2.2 AVGS System Integration

This element contains the work necessary to oversee the AVGS software development and ensure compliance in their technical documentation of the system's technical characteristics, including interface control documents, lower tier development progress reports and analyses, lower tier systems verification requirements and plans, and integration of the system elements into the operational scenario.

This element encompasses the effort required to plan, monitor, and certify the verification, validation and acceptance of the AVGS Software to ensure that they meet

the requirements and can execute the mission objectives as intended. Scope involves assurance that all supporting system elements are ready to support end to end tests, definition of key system test plans for completeness and ability to meet goals, review of key test scripts for timing and order of execution of command sequences. This work includes verification that the requirements are met, interfaces requirements are met, interoperability requirements are addressed, each requirement has a corresponding verification item and methods necessary to perform the verification is identified.

4.1.4.7.3 Safety & Mission Assurance

This element includes the technical and management efforts for developing and implementing the requirements for the safety and mission assurance function in the disciplines of safety, environmental protection, reliability, maintainability, supportability assurance, quality assurance, and operations. This effort also includes an independent review and assurance function over the design, development, testing, review, and certification/verification of AVGS Software.

4.1.4.7.3.1 Risk Identification and Analysis

This element will lead the risk assessment process in identification of risk, prioritizing the risk, and the mitigation planning. These processes shall be applied to the technical, schedule and cost aspects of the system. It includes oversight and insight in the planning and conducting of project/demonstrations for the identification of risk, and trade analysis to reduce the risk of the overall program. Also includes identification of risk mitigation task requirements, resources, and schedule.

4.1.4.7.3.1.1 AVGS Software Development Risk Reduction

This element includes activities required to reduce the risk of delivering the AVGS software on schedule. These activities would include performing an Independent Verification and Validation (IV&V) assessment and adding additional manpower.

4.1.4.7.3.1.2 AVGS System Risk Reduction

This element includes the support required to perform closed loop real-time Hardware In the Loop (HWIL) testing of OE flight control system for the proximity operations portion of the mission.

4.1.4.7.3.1.3 OE Risk Reduction

This element would include tasks that would reduce the risk of future Automated Rendezvous and Docking missions. These tasks may include the Guidance Navigation and Control (GN&C) analysis to verify flight vehicle control system performance or fluid coupling between two satellites.

4.1.4.7.4 Reserved

4.1.4.7.5 Design, Integration, and Test

This element is a collector for the design, integration, and testing of the Advanced Video Guidance System (AVGS) software part of the AVGS instrument. The AVGS will be

mounted on a chase vehicle to demonstrate autonomous rendezvous and closed loop proximity control between two co-orbiting satellites.

4.1.4.7.5.1 AVGS Software Development

This element encompasses the software development, modification, coding, and assessment. Detailed design activities include algorithm development, output formats to transmit fault codes, and implement software code suitable for integration on AVGS processors. Flight software verification will include verification test plans and verification testing. Orbital-Express specific revisions will be created using the existing AVGS software requirements and verification documents. This task also includes identification of AVGS software requirements which require modification to support OE mission profiles and target configurations.

4.1.4.7.5.2 AVGS Software Emulator

This element provides the support required to develop the OE specific AVGS software emulator by modifying the Demonstration of Automated Rendezvous Technology (DART) configuration AVGS software emulator to produce an emulator version usable for testing AVGS system behavior in the OE systems integration laboratory. The final software emulator should include provisions for reproducing test derived OE AVGS noise and latency characteristics. The element will include the delivery of a User's Guide.

4.1.4.7.5.3 AVGS Optical Characterization and Performance Testing

This element includes support of the AVGS system verification testing to verify system-level performance for the AVGS sensor unit, integrated software, and target hardware. Verification tests shall include optical system performance, data performance, and timing while operating under control of an AC2 vehicle computer or AC2 emulator in testing at Marshall Space Flight Center (MSFC) facilities.

4.1.4.7.5.4 OE Docking Mechanism Testing

This element includes the effort to conduct the testing to verify the design of the OE docking mechanism. The testing will be performed on the OE docking mechanism qualification unit.

4.1.4.7.5.5 AVGS System Level Open Loop I/F Testing

This element includes the effort required to perform system level open loop interface testing of the Boeing OE Sensor Suite in the flight robotics laboratory.

4.1.4.7.6 Element Operations

This element provides the support required for the AVGS functional testing and integration of the AVGS into the spacecraft and the real time OE mission support. Also included in this element are the pre-mission training exercises and simulations. Inputs to flight support documentation defining normal operation and anomaly recognition, analysis and resolution will be made as needed.

4.1.4.7.7 Reserved

4.1.4.8 X-37 Demonstration Program

This is the top level WBS for the X-37 Program. The X-37 Vehicle Program summary element refers to the advanced technology flight demonstrator vehicle (X-37) element of future space vehicles wherein, the objective is to reduce the cost of In-Space Transportation for going to and from low-Earth orbit with In-Space Transportation Systems that are responsive to civil, commercial and DOD missions. In support of future program objectives, the X-37 ALTV will be developed and flown as a test-bed with embedded technologies. As described in CLIN 14, the LDOV element of the X-37 Vehicle Program shall be limited to the effort associated with development of the following high-risk technologies: Carbon-Carbon and Carbon Silicon Carbide Hot Structures, Wing Leading Edge Tiles and other select TPS technologies considered high-risk. In addition the LDOV technology effort shall include a minimal level of support to provide needed inputs to the government for the continuation of aero-heating analysis, aerodynamic data base development and transfer of completed analysis and data bases from the Government to Boeing.

The work under many WBS elements has been postponed indefinitely pending future programmatic decisions. Consequently, such elements have been reserved for possible future work and marked accordingly.

4.1.4.8.1 X-37 Demonstration Program

The Long Duration Orbital Vehicle element refers to the development of Carbon-Carbon and Carbon Silicon Carbide Hot Structures, Wing Leading Edge Tiles and other select TPS technologies considered high-risk. In addition the LDOV technology effort includes a minimal level of support to provide needed inputs to the government for the continuation of aero-heating analysis and aerodynamic data base development and transfer of completed analysis and data bases from the Government to Boeing.

4.1.4.8.2 Systems Engineering Program Management

This task includes the systems engineering technical and management efforts for developing, directing, and integrating the engineering efforts for the X-37. This encompasses the effort to define the total system, conduct functional analysis and requirements flow down from the system specification to lower level specifications, the traceability of system requirements, verification and validation that the system design meets requirements. It also includes the definition and control of flight-to-ground segment and the conduct of program-level technical and design reviews. The Specialty Engineering functions of System Safety, Environmental Engineering, and Reliability and Maintainability, as well as Quality Assurance are also included in this task.

The Contractor shall provide the effort and resources required for the design, development, test, analysis, evaluation, and integration of a collapsible drogue chute system to ensure safe separation of the ALTV vehicle from the B-52 aircraft. The collapsible drogue chute shall provide an aerodynamically safe approach to separation from the B-52 that provides for not credible re-contact event. The collapsible drogue chute design and implementation shall meet the X-37 mission success requirements.

The Contractor shall perform technical management of collapsible drogue chute technical, cost and schedule risks.
The Contractor shall monitor collapsible drogue chute supplier activities during design, fabrication, assembly, qualification and acceptance testing of the collapsible drogue chute subsystem hardware.
The Contractor shall perform the following tasks:

4.1.4.8.3 ALTV

4.1.4.8.4 OV Flight Segment

4.1.4.8.5 Ground Segment (Ground Command, Control and Communication (GC3) Systems)

The X-37 ALTV Ground Command, Control & Communication (GC3) Systems element refers to the mission equipment system which provides the ability to control, monitor and analyze the X-37 ALT vehicle during vehicle ground checkout, range taxi/tow, atmospheric flight, and approach and landing phases of vehicle operation. The GC3 consists of a mobile flight operations control center, an X-37 system test rack, dGPS reference station, and a portable X-37 computer controller. The contractor shall provide Software Design Descriptions (DRD 998SW-001).

The Contractor shall limit effort in WBS element 1.4.9.5 and all sub-elements of 1.4.9.5 to the work required to implement the GC3 System for support of the ALTV.

4.1.4.8.6 Reserved for Launch Equipment and Logistics Support

4.1.4.8.7 Vehicle Assembly

This element refers to the planning and management of AIT activities, the assembly of structural components, the installation of subsystem equipment, the conduct of assembly/installation verification testing, environmental and functional testing and a final acceptance test to produce an integrated flight unit ready for demonstration testing.

The Contractor shall limit effort in WBS element 1.4.9.7 and all sub-elements of 1.4.9.7 to the work required for assembly of the ALTV.

4.1.4.8.8 Flight and Ground Operations

The Contractor shall limit effort in WBS element 1.4.9.8 and all sub-elements of 1.4.9.8 to the work required to implement Flight and Ground Operations in support of the ALTV.

ALTV

The Flight Test/Operations refers to the X-37 flight test and associated ground operations associated with the Approach and Landing Test (ALT) vehicle following the delivery to the test site. This includes test planning, test execution, and post-test analysis and reporting for tow/taxi tests, captive and drop test flights.

Reserved for LDOV

4.1.4.9 DART

4.1.5 Integration and Test

See Appendix A

4.1.5.1 Analysis and Design

See Appendix A.

4.1.5.2 Test

See Appendix A.

4.1.5.3 Assembly

See Appendix A.

4.1.6 Integrated Operations

See Appendix A

4.1.6.1 Operations Management

See Appendix A.

4.1.6.2 Operations Integration

See Appendix A.

4.1.6.2.1 Ground Operations Integration

See Appendix A.

4.1.6.2.2 Mission Operations Integration

See Appendix A.

4.1.6.2.3 Surface Operations Integration

See Appendix A.

4.1.6.3 Consolidated Systems Operations

See Appendix A.

4.1.6.3.1 Mission Integration

See Appendix A.

4.1.6.3.2 Ground Processing

See Appendix A.

4.1.6.3.2.1 Certification

See Appendix A.

4.1.6.3.2.2 Training and Simulation

See Appendix A.

4.1.6.3.2.3 Logistics
See Appendix A.

4.1.6.3.2.4 Launch Preparation Operations
See Appendix A.

4.1.6.3.2.5 Launch Operations
See Appendix A.

4.1.6.3.2.6 Landing and Recovery Operations
See Appendix A.

4.1.6.3.2.7 Launch Abort and Recovery
See Appendix A.

4.1.6.3.2.8 Range Operations
See Appendix A.

4.1.6.3.2.9 Retirement/Disposal
See Appendix A.

4.1.6.3.3 Mission Operations
See Appendix A.

4.1.6.3.3.1 Certification
See Appendix A.

4.1.6.3.3.2 Training and Simulation
See Appendix A.

4.1.6.3.3.3 Logistics
See Appendix A.

4.1.6.3.3.4 Flight Design and Flight Planning
See Appendix A.

4.1.6.3.3.5 Payload Planning
See Appendix A.

4.1.6.3.3.6 Flight Operations Products and Procedures Development
See Appendix A.

4.1.6.3.3.7 Flight Operations
See Appendix A.

4.1.6.3.3.8 Retirement Disposal

See Appendix A.

4.1.6.3.4 Reserved

4.1.6.3.5 Communications

See Appendix A.

4.1.7 Ground Systems

This effort includes development and operations of common and multi-use facilities /systems such as a mission control center, communication networks, pre-launch ground processing infrastructure, etc. supporting human exploration and supporting Crew missions as well as robotic precursor missions. This element includes all common and multi-use facilities/systems that do not fly as part of a mission in the support of Mission Operations and pre-launch processing operations. The complex of equipment, HW, SW, and facilities/systems required to assemble, integrate, Testing, and monitor the Exploration Missions systems during pre-launch processing, launch simulations, flight simulations, rehearsals, launch operations, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include spacecraft and instrument Testing beds, post-launch flight SW development equipment, or interfaces to such capability. This element also includes all required unique support systems to Testing, process, certify, operate, and maintain the common ground systems.

4.1.7.1 Ground Systems Management Team

See Appendix B.

4.1.7.2 RFP/SEB Support

4.1.7.3 Ground Systems IPT Support

See Appendix B.

4.1.7.3.1 Systems Engineering & Integration

See Appendix B.

4.1.7.3.2 Constellation Systems Analysis

See Appendix B.

4.1.7.3.3 Cost Engineering

See Appendix B.

4.1.7.3.4 Safety & Mission Assurance

See Appendix B.

4.1.7.3.5 Operations

See Appendix B.

4.1.7.3.6 Human Centered

See Appendix B.

4.1.7.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.1.7.3.8 Command, Control & Communications

See Appendix B.

4.1.7.3.9 Ground Infrastructure

See Appendix B.

4.1.7.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.1.7.3.11 Propulsion & Fluids

See Appendix B.

4.1.7.3.12 Power Systems

See Appendix B.

4.1.7.3.13 Computer, Software, Automation

See Appendix B.

4.1.7.3.14 Robotics

See Appendix B.

4.1.7.4 Ground Systems Contract End Item (CEI) Prime Contractor

See Appendix B

4.1.7.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.1.7.4.2 System Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.1.7.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.1.7.4.4 Reserved

4.1.7.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.1.7.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.1.7.5 Ground Processing Facilities and Systems

For the given SS spiral, this element captures the effort required to implement the common, multi-use facilities, systems and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor and launch the given system, including integrated test, with other Spiral I systems. These activities include work necessary to design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the ground processing facilities and systems.

4.1.7.6 Launch Facilities and Systems

This element encompasses the effort required to implement the common, multi-use facilities, systems, and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor, and launch the Spiral I launch vehicle. These activities include work necessary to design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the launch facilities and systems.

4.1.7.7 Mission Control Facilities and Systems

This element provides the infrastructure necessary for the overall command and control authority for the SS missions. The capabilities required include voice and video communications, telemetry reception, and data and command uplink to the SS spacecraft elements. In addition to these basic capabilities, the facility will host the necessary software tools and applications necessary to support operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc), and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc). As the SS elements are further defined, it is anticipated that additional capabilities will be incorporated into the mission control facility.

4.1.7.7.1 System of Systems Command

This element provides for the development and sustaining of all necessary software applications, and associated hardware, to support command loads builds - either discrete commands or software loads, verification of the correct content, transmission to and verification that the command was correctly received from the desired SS element, and reception of positive feedback from the SS element that the commands have been successfully executed. This element also provides for the development and sustaining of the processes and tools necessary to accomplish the command reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.1.7.7.2 System of Systems Telemetry

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capability to receive, store and retrieve, process, and display the telemetry from the various SS elements. This element also provides for the development and sustaining of the processes and tools necessary for data telemetry reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.1.7.7.3 Voice and Video Communications

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capabilities for communications between the flight crew and the mission control facilities. This includes the transmission, reception, encryption, processing, and recorded storage and retrieval of communications information.

4.1.7.7.4 Mission Control Center (MCC)

This element covers the portion of the facility and systems to provide a central location for overall mission command and control. Within the Mission Control Center (MCC), this element provides for the development, sustaining, and hosting of the software tools and applications, and associated hardware, necessary to support missions operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc) tools, and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc).

4.1.7.7.5 Software Development and Sustainment

This element provides for the development and sustaining efforts required for all necessary software applications required by the mission control facilities and systems.

4.1.7.8 Training/Simulation Facilities and Systems

This element provides for the development and sustaining of the facilities and systems necessary to train and prepare ground operations personnel, flight controllers, and flight crew to perform their assigned tasks. The facilities and systems include flight simulators covering all facets of the mission, mockups, computer-based trainers (CBT), Part-Task Trainers (PTT), Flight Controller Trainers (FCT), and any other trainer as required by the Mission. This element will also address any necessary integration between one or more trainers/simulators and with the mission control facilities to support training between the flight control team and the flight crews, and to support various product verification tasks (e.g., procedure verification).

4.1.7.8.1 Ground Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Ground Operations personnel to perform the tasks required in the pre-flight processing of the SS elements, preparation leading up to launch operations, and rescue of the flight crew.

4.1.7.8.2 Flight Crew/Flight Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Flight Operations personnel to perform the tasks required in the pre-flight preparations for and eventual execution of an SS mission.

4.1.7.8.3 Surface Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Surface Operations personnel to perform the tasks required in the pre-flight preparations for and eventual execution of SS surface operations.

4.1.7.9 Communications Facilities and Systems

This element describes the communications infrastructure that consists of an administrative segment, an operations segment, and a mission support segment. The administrative communication facility and systems include office telephones, office networks/data systems, paging & area warning, broadband communications distribution system, and the associated cable plant. The operational communication facilities and systems include the operational intercom system, operational television system, photo optic control system, timing and countdown system, wideband transmission systems, frequency division multiplex system, and any new or other communication facility and systems required but not yet identified. The mission support segment facilities and systems include the global networks that provide data, voice, and video communications among the government and contractor support sites to the mission.

4.1.8 Crew Exploration Vehicle (CEV)

The Crew Exploration Vehicle (CEV) is the spacecraft that provides transportation for the crew to and from space. The CEV does not include the launch vehicle required to boost the spacecraft into orbit. The CEV will initially operate in low-Earth orbit (LEO), and includes subsystems for functions such as crew survival during ascent, environmental control and life support, communications, navigation and control, power, thermal control, thermal protection, radiation protection, propulsion, docking, and recovery. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CEV as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.1.8.1 CEV Management Team

See Appendix B

4.1.8.2 RFP/SEB Support

See Appendix B

4.1.8.3 CEV IPT Support

See Appendix B.

4.1.8.3.1 Systems Engineering & Integration

See Appendix B.

4.1.8.3.2 Constellation Systems Analysis

See Appendix B.

4.1.8.3.3 Cost Engineering

See Appendix B.

4.1.8.3.4 Safety & Mission Assurance

See Appendix B.

4.1.8.3.5 Operations

See Appendix B.

4.1.8.3.6 Human Centered

See Appendix B.

4.1.8.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.1.8.3.8 Command, Control & Communications

See Appendix B.

4.1.8.3.9 Ground Infrastructure

See Appendix B.

4.1.8.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.1.8.3.11 Propulsion & Fluids

See Appendix B.

4.1.8.3.12 Power Systems

See Appendix B.

4.1.8.3.13 Computer, Software & Automation

See Appendix B.

4.1.8.3.14 Robotics

See Appendix B.

4.1.8.4 CEV Prime Contractors

SEE APPENDIX B

4.1.8.4.1 System Management

See Appendix B

4.1.8.4.2 Systems Engineering

See Appendix B

4.1.8.4.3 Safety and Mission Assurance

See Appendix B

4.1.8.4.4 Reserved

4.1.8.4.5 Integration and Test

See Appendix B

4.1.8.4.6 Operations

See Appendix B

4.1.8.4.7 Crew Exploration Vehicle (CEV) Ground Systems

See Appendix B.

4.1.8.4.8 Contract End Item(s)

To be provided by CEV management.

4.1.9 Crew Launch Vehicle (CLV)

The Crew Launch Vehicle (CLV) is the part of the human-rated launch system that delivers the CEV to LEO. The CLV includes the launch vehicle stages and subsystems such as tanks and plumbing, supporting structures, propulsion, controls, communications, and power. Also included is any CLV specific launch support infrastructure. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CLV, as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.1.9.1 Crew Launch Vehicle Management Team

See Appendix B

4.1.9.2 RFP/SEB Support

See Appendix B

4.1.9.3 Crew Launch Vehicle IPT Support

See Appendix B

4.1.9.3.1 Systems Engineering & Integration

See Appendix B.

4.1.9.3.2 Constellation Systems Analysis

See Appendix B.

4.1.9.3.3 Cost Engineering

See Appendix B.

4.1.9.3.4 Safety & Mission Assurance

See Appendix B.

4.1.9.3.5 Operations

See Appendix B.

4.1.9.3.6 Human Centered

See Appendix B.

4.1.9.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.1.9.3.8 Command, Control & Communications

See Appendix B.

4.1.9.3.9 Ground Infrastructure

See Appendix B.

4.1.9.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.1.9.3.11 Propulsion & Fluids

See Appendix B.

4.1.9.3.12 Power Systems

See Appendix B.

4.1.9.3.13 Computer, Software & Automation

See Appendix B.

4.1.9.3.14 Robotics

See Appendix B.

4.1.9.4 Crew Launch Vehicle Prime Contractors

See Appendix B

4.1.9.4.1 System Management

See Appendix B

4.1.9.4.2 Systems Engineering

See Appendix B

4.1.9.4.3 Safety and Mission Assurance

See Appendix B

4.1.9.4.4 Reserved

4.1.9.4.5 Integration and Test

See Appendix B

4.1.9.4.6 Operations

See Appendix B

4.1.9.4.7 Crew Launch Vehicle Ground Systems

The work to develop unique HRLV ground systems for the given system of systems spiral.

4.1.9.4.8 Launch Vehicle

TBD

4.1.10 In-Space Transportation Systems

TBD

4.1.10.1 In-Space Transportation Systems Management Team

See Appendix B

4.1.10.2 RFP/SEB Support

See Appendix B

4.1.10.3 In-In-Space Transportation Systems IPT Support

See Appendix B

4.1.10.3.1 Systems Engineering & Integration

See Appendix B

4.1.10.3.2 Constellation Systems Analysis

See Appendix B

4.1.10.3.3 Cost Engineering

See Appendix B

4.1.10.3.4 Safety & Mission Assurance

See Appendix B

4.1.10.3.5 Operations

See Appendix B

4.1.10.3.6 Human Centered

See Appendix B

4.1.10.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B

4.1.10.3.8 Command, Control & Communciations

See Appendix B

4.1.10.3.9 Ground Infrastructure

See Appendix B

4.1.10.3.10 Aerosciences & Flight Mechanics

See Appendix B

4.1.10.3.11 Propulsion & Fluids

See Appendix B

4.1.10.3.12 Power Systems

See Appendix B

4.1.10.3.13 Computer, Software, Automation

See Appendix B

4.1.10.3.14 Robotics

See Appendix B

4.1.10.4 In-In-Space Transportation Systems Prime Contractors

See Appendix B

4.1.10.4.1 System Management

See Appendix B

4.1.10.4.2 Systems Engineering

See Appendix B

4.1.10.4.3 Safety and Mission Assurance

See Appendix B

4.1.10.4.4 Reserved

See Appendix B

4.1.10.4.5 Integration and Test

See Appendix B

4.1.10.4.6 Operations

See Appendix B

4.1.10.4.7 In-Space Transportation Ground Systems

See Appendix B

4.1.10.4.8 In-Space Transportation Contract End Item

See Appendix B

4.1.11 Human Support Systems

Human Support Systems (HSS) include systems and equipment that permit and facilitate crew operations in environments otherwise unsuitable for human activities. Examples of HSS include extravehicular activity (EVA) suits and backpacks, maneuvering units, robot assistants, and special tools. HSS does not include equipment integrated into the crew exploration vehicle or other modules that permit servicing or recharging of the HSS. Each HSS may be developed as a single end item or multiple modules that constitute an end item. Typically, a system might include subsystems such as power, communications, and environmental control to permit the crew to operate autonomously from the primary vehicle. HSS also includes all design, development, production, assembly, and test efforts to deliver the completed and qualified system.

4.1.11.1 Human Support Systems Management Team

See Appendix B

4.1.11.2 RFP/SEB Support

See Appendix B

4.1.11.3 Human Support Systems IPT Support

See Appendix B

4.1.11.3.1 Systems Engineering & Integration

See Appendix B

4.1.11.3.2 Constellation Systems Analysis

See Appendix B

4.1.11.3.3 Cost Engineering

See Appendix B

4.1.11.3.4 Safety & Mission Assurance

See Appendix B

4.1.11.3.5 Operations

See Appendix B

4.1.11.3.6 Human Centered

See Appendix B

4.1.11.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B

4.1.11.3.8 Command, Control & Communciations

See Appendix B

4.1.11.3.9 Ground Infrastructure

See Appendix B

4.1.11.3.10 Aerosciences & Flight Mechanics

See Appendix B

4.1.11.3.11 Propulsion & Fluids

See Appendix B

4.1.11.3.12 Power Systems

See Appendix B

4.1.11.3.13 Computer, Software, Automation

See Appendix B

4.1.11.3.14 Robotics

See Appendix B

4.1.11.4 Human Support Systems Prime Contractors

See Appendix B

4.1.11.4.1 System Management

See Appendix B

4.1.11.4.2 Systems Engineering

See Appendix B

4.1.11.4.3 Safety and Mission Assurance

See Appendix B

4.1.11.4.4 Reserved

4.1.11.4.5 Integration and Test

See Appendix B

4.1.11.4.6 Operations

See Appendix B

4.1.11.4.7 Human Support Ground Systems

See Appendix B

4.1.11.4.8 EVA System

This element includes the work required to develop systems for all extravehicular activity during Exploration missions. This effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility aids. For the given SS spiral, the work to develop the systems is required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

4.1.12 In-Space Systems

In-Space Systems (InSS) includes spacecraft supporting both human and robotic exploration of the Moon, Mars, and other solar system bodies. This element can include logistics modules carrying fuel and supplies; spacecraft positioned to support communication, navigation, and/or reconnaissance requirements; and rendezvous/docking and robotic vehicles to support assembly in space. In-Space Systems will typically be free-flying spacecraft and include the subsystems to provide communications, command, and control, power, thermal control, and propulsion for orbit maintenance, maneuvering, and docking. In-Space Systems will also include all modifications/additions to the unique ground based communications assets(such as the Deep Space Network) to provide communications and navigation functions for human and robotic exploration. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified InSS, as well as the necessary unique support equipment to test, process, certify, transport, and operate the InSS..

4.1.12.1 In-Space Systems Management Team

See Appendix B

4.1.12.2 RFP/SEB Support

See Appendix B

4.1.12.3 In-Space Systems IPT Support

See Appendix B

4.1.12.3.1 Systems Engineering & Integration

See Appendix B

4.1.12.3.2 Constellation Systems Analysis

See Appendix B

4.1.12.3.3 Cost Engineering

See Appendix B

4.1.12.3.4 Safety & Mission Assurance
See Appendix B

4.1.12.3.5 Operations
See Appendix B

4.1.12.3.6 Human Centered
See Appendix B

4.1.12.3.7 Structural, Mechanical, Materials & Manufacturing
See Appendix B

4.1.12.3.8 Command, Control & Communications
See Appendix B

4.1.12.3.9 Ground Infrastructure
See Appendix B

4.1.12.3.10 Aerosciences & Flight Mechanics
See Appendix B

4.1.12.3.11 Propulsion & Fluids
See Appendix B

4.1.12.3.12 Power Systems
See Appendix B

4.1.12.3.13 Computer, Software, Automation
See Appendix B

4.1.12.3.14 Robotics
See Appendix B

4.1.12.4 In-Space Systems Prime Contractor
See Appendix B

4.1.12.4.1 System Management
See Appendix B

4.1.12.4.2 Systems Engineering
See Appendix B

4.1.12.4.3 Safety and Mission Assurance
See Appendix B

4.1.12.4.4 Reserved

4.1.12.4.5 Integration and Test

See Appendix B

4.1.12.4.6 Operations

See Appendix B

4.1.12.4.7 In-Space Contract End Item Systems

See Appendix B

4.1.12.4.8 In-Space Systems Contract End Item

4.1.13 Robotic Mission Systems

Robotic Precursor Systems (RPS) include a range of robotic missions directly supporting human exploration. The purpose of the RPS missions includes characterizing Exploration destinations, validating key technologies supporting exploration, and preparing for and supporting future human missions. Robotic Precursor Systems include Orbiters and Landers and the associated subsystems necessary to accomplish the specific mission.

4.1.13.1 System Management

See Appendix B

4.1.13.2 Systems Engineering

See Appendix B

4.1.13.3 Safety and Mission Assurance

See Appendix B

4.1.13.4 Reserved

4.1.13.5 Integration and Test

See Appendix B

4.1.13.6 Operations

See Appendix B

4.1.13.7 Robotic Precursor Contract End Item Systems

See Appendix B

4.1.13.8 Lunar Reconnaissance Orbiter

This element encompasses all the work (data, products, and services) required to develop, deliver, and operate a lunar mapping reconnaissance orbiter. It includes the spacecraft, payload, launch vehicle, mission operation, ground system, and the management, systems

engineering, and mission assurance elements necessary for successfully delivering the lunar topographic and resource data products.

4.1.13.9 Lunar Robotic Lander

This element encompasses all the work (data, products and services) required to develop, deliver, and operate a robotic lander on the surface of the moon. It includes the spacecraft, payload, launch vehicle, mission operation, ground system and the management, systems engineering, and mission assurance elements necessary for successfully delivering the lunar surface resource verification products.

4.2 System of Systems II

Details of all elements in Sections 4.2.1 through 4.2.6 can be found in Appendix A of this document.

4.2.1 System Management

See Appendix A

4.2.1.1 Program/Project Management

See Appendix A

4.2.1.2 Business Management

See Appendix A

4.2.1.3 Information Management

See Appendix A

4.2.1.4 Administrative

See Appendix A

4.2.1.5 Requirements Management

See Appendix A

4.2.1.6 Acquisition Management

See Appendix A

4.2.1.7 Comprehensive Risk Management

See Appendix A

4.2.1.8 Supportability and Integrated Logistics Support Management

See Appendix A

4.2.2 System of Systems Engineering

See Appendix A

4.2.2.1 Engineering Management

See Appendix A

4.2.2.2 Requirements Definition

See Appendix A

4.2.2.3 Configuration and Data Management

See Appendix A

4.2.2.4 Risk Identification and Analysis

See Appendix A

4.2.2.5 System Definition

See Appendix A

4.2.2.6 System Integration

See Appendix A

4.2.2.7 Integrated Logistics Support

See Appendix A

4.2.2.8 Inter Discipline Team (IDT) Activity

See Appendix A

4.2.3 Safety and Mission Assurance

See Appendix A

4.2.3.1 Management and Administration

See Appendix A

4.2.3.1.1 Business Management

See Appendix A

4.2.3.2 Safety and Mission Assurance (S&MA) Integration

See Appendix A

4.2.3.2.1 External Assessment

See Appendix A

4.2.3.3 Safety and Mission Assurance Panels

See Appendix A

4.2.3.3.1 RMS Review Panels

See Appendix A

4.2.3.4 Safety, Health and Environment Assurance (SHEA)

See Appendix A

4.2.3.4.1 Occupational (Industrial) Safety

See Appendix A

4.2.3.4.2 Occupational Health

See Appendix A

4.2.3.4.3 Environmental Protection

See Appendix A

4.2.3.5 Reliability and Maintainability

See Appendix A

4.2.3.5.1 Reliability

See Appendix A

4.2.3.5.2 Maintainability

See Appendix A

4.2.3.6 Product Assurance

See Appendix A

4.2.3.6.1 Electrical, Electronic, Electromechanical (EEE) Parts

See Appendix A

4.2.3.6.2 Materials and Processes Product Assurance

See Appendix A

4.2.3.7 Software Assurance

See Appendix A

4.2.3.8 Operations Safety and Mission Assurance (S&MA)

See Appendix A

4.2.3.9 Human Rating and Crew Survival

See Appendix A

4.2.3.10 Nuclear Safety

See Appendix A

4.2.4 Advanced Development

See Appendix A

4.2.4.1 Technology Integration

See Appendix A

4.2.5 Integration and Test

See Appendix A

4.2.5.1 Analysis and Design

See Appendix A

4.2.5.2 Test

See Appendix A

4.2.5.3 Assembly

See Appendix A

4.2.6 Integrated Operations

See Appendix A

4.2.6.1 Operations Management

See Appendix A

4.2.6.2 Operations Integration

See Appendix A

4.2.6.2.1 Ground Operations Integration

See Appendix A

4.2.6.2.2 Mission Operations Integration

See Appendix A

4.2.6.2.3 Surface Operations Integration

See Appendix A

4.2.6.3 Consolidated Systems Operations

See Appendix A

4.2.6.3.1 Mission Integration

See Appendix A

4.2.6.3.2 Ground Processing

See Appendix A

4.2.6.3.3 Mission Operations

See Appendix A

4.2.6.3.4 Surface Operations

See Appendix A

4.2.6.3.5 Communications

See Appendix A

4.2.7 Ground Systems

This effort includes development and operations of common and multi-use facilities /systems such as a mission control center, communication networks, pre-launch ground

processing infrastructure, etc. supporting human exploration and supporting Crew missions as well as robotic precursor missions. This element includes all common and multi-use facilities/systems that do not fly as part of a mission in the support of Mission Operations and pre-launch processing operations. The complex of equipment, HW, SW, and facilities/systems required to assemble, integrate, Testing, and monitor the Exploration Missions systems during pre-launch processing, launch simulations, flight simulations, rehearsals, launch operations, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include spacecraft and instrument Testing beds, post-launch flight SW development equipment, or interfaces to such capability. This element also includes all required unique support systems to Testing, process, certify, operate, and maintain the common ground systems.

4.2.7.1 Ground Systems Management Team

See Appendix B.

4.2.7.2 RFP/SEB Support

See Appendix B

4.2.7.3 Ground Systems IPT Support

See Appendix B.

4.2.7.3.1 Systems Engineering & Integration

See Appendix B.

4.2.7.3.2 Constellation Systems Analysis

See Appendix B.

4.2.7.3.3 Cost Engineering

See Appendix B.

4.2.7.3.4 Safety & Mission Assurance

See Appendix B.

4.2.7.3.5 Operations

See Appendix B.

4.2.7.3.6 Human Centered

See Appendix B.

4.2.7.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.2.7.3.8 Command, Control & Communications

See Appendix B.

4.2.7.3.9 Ground Infrastructure

See Appendix B.

4.2.7.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.2.7.3.11 Propulsion & Fluids

See Appendix B.

4.2.7.3.12 Power Systems

See Appendix B.

4.2.7.3.13 Computer, Software, Automation

See Appendix B.

4.2.7.3.14 Robotics

See Appendix B.

4.2.7.4 Ground Systems Contract End Item (CEI) Prime Contractor

4.2.7.4.1 System Management

See Appendix B

4.2.7.4.2 System Engineering

See Appendix B

4.2.7.4.3 Safety and Mission Assurance

See Appendix B

4.2.7.4.4 Reserved

4.2.7.4.5 Integration and Test

See Appendix B

4.2.7.4.6 Operations

See Appendix B

4.2.7.5 Ground Processing Facilities and Systems

For the given SS spiral, this element captures the effort required to implement the common, multi-use facilities, systems and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor and launch the given system, including integrated test, with other Spiral I systems. These activities include work necessary to design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the ground processing facilities and systems.

4.2.7.6 Launch Facilities and Systems

This element encompasses the effort required to implement the common, multi-use facilities, systems, and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor, and launch the Spiral I launch vehicle. These activities include work necessary to design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the launch facilities and systems.

4.2.7.7 Mission Control Facilities and Systems

This element provides the infrastructure necessary for the overall command and control authority for the SS missions. The capabilities required include voice and video communications, telemetry reception, and data and command uplink to the SS spacecraft elements. In addition to these basic capabilities, the facility will host the necessary software tools and applications necessary to support operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc), and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc). As the SS elements are further defined, it is anticipated that additional capabilities will be incorporated into the mission control facility.

4.2.7.7.1 System of Systems Command

This element provides for the development and sustaining of all necessary software applications, and associated hardware, to support command loads builds - either discrete commands or software loads, verification of the correct content, transmission to and verification that the command was correctly received from the desired SS element, and reception of positive feedback from the SS element that the commands have been successfully executed. This element also provides for the development and sustaining of the processes and tools necessary to accomplish the command reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.2.7.7.2 System of Systems Telemetry

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capability to receive, store and retrieve, process, and display the telemetry from the various SS elements. This element also provides for the development and sustaining of the processes and tools necessary for data telemetry reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.2.7.7.3 Voice and Video Communications

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capabilities for communications between the flight crew and the mission control facilities. This includes the transmission, reception, encryption, processing, and recorded storage and retrieval of communications information.

4.2.7.7.4 Mission Control Center (MCC)

This element covers the portion of the facility and systems to provide a central location for overall mission command and control. Within the Mission Control Center (MCC), this element provides for the development, sustaining, and hosting of the software tools and applications, and associated hardware, necessary to support missions operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc) tools, and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc).

4.2.7.7.5 Software Development and Sustainment

This element provides for the development and sustaining efforts required for all necessary software applications required by the mission control facilities and systems.

4.2.7.8 Training/Simulation Facilities and Systems

This element provides for the development and sustaining of the facilities and systems necessary to train and prepare ground operations personnel, flight controllers, and flight crew to perform their assigned tasks. The facilities and systems include flight simulators covering all facets of the mission, mockups, computer-based trainers (CBT), Part-Task Trainers (PTT), Flight Controller Trainers (FCT), and any other trainer as required by the Mission. This element will also address any necessary integration between one or more trainers/simulators and with the mission control facilities to support training between the flight control team and the flight crews, and to support various product verification tasks (e.g., procedure verification).

4.2.7.8.1 Ground Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Ground Operations personnel to perform the tasks required in the pre-flight processing of the SS elements, preparation leading up to launch operations, and rescue of the flight crew.

4.2.7.8.2 Flight Crew/Flight Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Flight Operations personnel to perform the tasks required in the pre-flight preparations for and eventual execution of an SS mission.

4.2.7.8.3 Surface Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Surface Operations personnel to perform the tasks required in the pre-flight preparations for and eventual execution of SS surface operations.

4.2.7.9 Communications Facilities and Systems

This element describes the communications infrastructure that consists of an administrative segment, an operations segment, and a mission support segment. The

administrative communication facility and systems include office telephones, office networks/data systems, paging & area warning, broadband communications distribution system, and the associated cable plant. The operational communication facilities and systems include the operational intercom system, operational television system, photo optic control system, timing and countdown system, wideband transmission systems, frequency division multiplex system, and any new or other communication facility and systems required but not yet identified. The mission support segment facilities and systems include the global networks that provide data, voice, and video communications among the government and contractor support sites to the mission.

4.2.8 Crew Exploration Vehicle (CEV)

The Crew Exploration Vehicle (CEV) is the spacecraft that provides transportation for the crew to and from space. The CEV does not include the launch vehicle required to boost the spacecraft into orbit. The CEV will initially operate in low-Earth orbit (LEO), and includes subsystems for functions such as crew survival during ascent, environmental control and life support, communications, navigation and control, power, thermal control, thermal protection, radiation protection, propulsion, docking, and recovery. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CEV as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.2.8.1 CEV Management Team

See Appendix B

4.2.8.2 RFP/SEB Support

See Appendix B

4.2.8.3 CEV IPT Support

SEE APPENDIX B

4.2.8.3.1 Systems Engineering & Integration

See Appendix B.

4.2.8.3.2 Constellation Systems Analysis

See Appendix B.

4.2.8.3.3 Cost Engineering

See Appendix B.

4.2.8.3.4 Safety & Mission Assurance

See Appendix B.

4.2.8.3.5 Operations

See Appendix B.

4.2.8.3.6 Human Centered

See Appendix B.

4.2.8.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.2.8.3.8 Command, Control & Communications

See Appendix B.

4.2.8.3.9 Ground Infrastructure

See Appendix B.

4.2.8.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.2.8.3.11 Propulsion & Fluids

See Appendix B.

4.2.8.3.12 Power Systems

See Appendix B.

4.2.8.3.13 Computer, Software & Automation

See Appendix B.

4.2.8.3.14 Robotics

See Appendix B.

4.2.8.4 CEV Prime Contractors

SEE APPENDIX B

4.2.8.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.2.8.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.2.8.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.2.8.4.4 Reserved

4.2.8.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.2.8.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.2.8.4.7 Crew Exploration Vehicle (CEV) Ground Systems

See Appendix B Tier 3 Constellation Functional Work Template.

4.2.8.4.8 Contract End Item(s)

To be provided by CEV management.

4.2.9 Crew Launch Vehicle (CLV)

The Crew Launch Vehicle (CLV) is the part of the human-rated launch system that delivers the CEV to LEO. The CLV includes the launch vehicle stages and subsystems such as tanks and plumbing, supporting structures, propulsion, controls, communications, and power. Also included is any CLV specific launch support infrastructure. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CLV, as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.2.9.1 Crew Launch Vehicle Management Team

SEE APPENDIX B

4.2.9.2 RFP/SEB Support

4.2.9.3 Crew Launch Vehicle IPT Support

SEE APPENDIX B

4.2.9.3.1 Systems Engineering & Integration

See Appendix B.

4.2.9.3.2 Constellation Systems Analysis

See Appendix B.

4.2.9.3.3 Cost Engineering

See Appendix B.

4.2.9.3.4 Safety & Mission Assurance

See Appendix B.

4.2.9.3.5 Operations

See Appendix B.

4.2.9.3.6 Human Centered

See Appendix B.

4.2.9.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.2.9.3.8 Command, Control & Communications

See Appendix B.

4.2.9.3.9 Ground Infrastructure

See Appendix B.

4.2.9.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.2.9.3.11 Propulsion & Fluids

See Appendix B.

4.2.9.3.12 Power Systems

See Appendix B.

4.2.9.3.13 Computer, Software & Automation

See Appendix B.

4.2.9.3.14 Robotics

See Appendix B.

4.2.9.4 Crew Launch Vehicle Prime Contractors

SEE APPENDIX B

4.2.9.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.2.9.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.2.9.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.2.9.4.4 Reserved

4.2.9.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.2.9.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.2.9.4.7 Crew Launch Vehicle Ground Systems

The work to develop unique HRLV ground systems for the given system of systems spiral.

4.2.9.4.8 Phase A/B Launch Vehicle Demo

SEE APPENDIX B

4.2.9.4.9 Launch Vehicle Contract End Item

SEE APPENDIX B

4.2.10 In-Space Transportation Systems

TBD

4.2.10.1 In-Space Transportation Systems Management Team

SEE APPENDIX B

4.2.10.2 RFP/SEB Support

SEE APPENDIX B

4.2.10.3 In-Space Transportation Systems IPT Support

SEE APPENDIX B

4.2.10.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.2.10.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.2.10.3.3 Cost Engineering

SEE APPENDIX B

4.2.10.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.2.10.3.5 Operations

SEE APPENDIX B

4.2.10.3.6 Human Centered

SEE APPENDIX B

4.2.10.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.2.10.3.8 Command, Control & Communciations

SEE APPENDIX B

4.2.10.3.9 Ground Infrastructure

SEE APPENDIX B

4.2.10.3.10 Aerosciences & Flight Mechanics

SEE APPENDIX B

4.2.10.3.11 Propulsion & Fluids

SEE APPENDIX B

4.2.10.3.12 Power Systems

SEE APPENDIX B

4.2.10.3.13 Computer, Software, Automation

SEE APPENDIX B

4.2.10.3.14 Robotics

SEE APPENDIX B

4.2.10.4 In-Space Transportation Systems Prime Contractors

SEE APPENDIX B

4.2.10.4.1 System Management

See Appendix B

4.2.10.4.2 Systems Engineering

See Appendix B

4.2.10.4.3 Safety and Mission Assurance

See Appendix B

4.2.10.4.4 Reserved

See Appendix B

4.2.10.4.5 Integration and Test

See Appendix B

4.2.10.4.6 Operations

See Appendix B

4.2.10.4.7 In-Space Transportation Ground Systems

See Appendix B

4.2.10.4.8 In-Space Transportation CEI

See Appendix B

4.2.11 Human Support Systems

Human Support Systems (HSS) include systems and equipment that permit and facilitate crew operations in environments otherwise unsuitable for human activities. Examples of HSS include extravehicular activity (EVA) suits and backpacks, maneuvering units, robot

assistants, and special tools. HSS does not include equipment integrated into the crew exploration vehicle or other modules that permit servicing or recharging of the HSS. Each HSS may be developed as a single end item or multiple modules that constitute an end item. Typically, a system might include subsystems such as power, communications, and environmental control to permit the crew to operate autonomously from the primary vehicle. HSS also includes all design, development, production, assembly, and test efforts to deliver the completed and qualified system.

4.2.11.1 Human Support Systems Management Team

SEE APPENDIX B

4.2.11.2 RFP/SEB Support

SEE APPENDIX B

4.2.11.3 Human Support Systems IPT Support

SEE APPENDIX B

4.2.11.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.2.11.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.2.11.3.3 Cost Engineering

SEE APPENDIX B

4.2.11.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.2.11.3.5 Operations

SEE APPENDIX B

4.2.11.3.6 Human Centered

SEE APPENDIX B

4.2.11.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.2.11.3.8 Command, Control & Communciations

SEE APPENDIX B

4.2.11.3.9 Ground Infrastructure

SEE APPENDIX B

4.2.11.3.10 Aerosciences & Flight Mechanics

SEE APPENDIX B

4.2.11.3.11 Propulsion & Fluids

SEE APPENDIX B

4.2.11.3.12 Power Systems

SEE APPENDIX B

4.2.11.3.13 Computer, Software, Automation

SEE APPENDIX B

4.2.11.3.14 Robotics

SEE APPENDIX B

4.2.11.4 Human Support Systems Prime Contractors

SEE APPENDIX B

4.2.11.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.2.11.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.2.11.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.2.11.4.4 Reserved

4.2.11.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.2.11.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.2.11.4.7 Human Support Ground Systems

See Appendix B Tier 3 Constellation Functional Work Template

4.2.11.4.8 EVA System

This element includes the work required to develop systems for all extravehicular activity during Exploration missions. This effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility aids. For the given SS spiral, the work to develop the systems is required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

4.2.12 In-Space Systems

In-Space Systems (InSS) includes spacecraft supporting both human and robotic exploration of the Moon, Mars, and other solar system bodies. This element can include logistics modules carrying fuel and supplies; spacecraft positioned to support communication, navigation, and/or reconnaissance requirements; and rendezvous/docking and robotic vehicles to support assembly in space. In-Space Systems will typically be free-flying spacecraft and include the subsystems to provide communications, command, and control, power, thermal control, and propulsion for orbit maintenance, maneuvering, and docking. In-Space Systems will also include all modifications/additions to the unique ground based communications assets(such as the Deep Space Network) to provide communications and navigation functions for human and robotic exploration. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified InSS, as well as the necessary unique support equipment to test, process, certify, transport, and operate the InSS..

4.2.12.1 In-Space Systems Management Team

SEE APPENDIX B

4.2.12.2 RFP/SEB Support

SEE APPENDIX B

4.2.12.3 In-Space Systems IPT Support

SEE APPENDIX B

4.2.12.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.2.12.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.2.12.3.3 Cost Engineering

SEE APPENDIX B

4.2.12.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.2.12.3.5 Operations

SEE APPENDIX B

4.2.12.3.6 Human Centered

SEE APPENDIX B

4.2.12.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.2.12.3.8 Command, Control & Communications
SEE APPENDIX B

4.2.12.3.9 Ground Infrastructure
SEE APPENDIX B

4.2.12.3.10 Aerosciences & Flight Mechanics
SEE APPENDIX B

4.2.12.3.11 Propulsion & Fluids
SEE APPENDIX B

4.2.12.3.12 Power Systems
SEE APPENDIX B

4.2.12.3.13 Computer, Software, Automation
SEE APPENDIX B

4.2.12.3.14 Robotics
SEE APPENDIX B

4.2.12.4 In-Space Systems Prime Contractor
SEE APPENDIX B

4.2.12.4.1 System Management
See Appendix B Tier 3 Constellation Functional Work Template

4.2.12.4.2 Systems Engineering
See Appendix B Tier 3 Constellation Functional Work Template

4.2.12.4.3 Safety and Mission Assurance
See Appendix B Tier 3 Constellation Functional Work Template

4.2.12.4.4 Reserved

4.2.12.4.5 Integration and Test
See Appendix B Tier 3 Constellation Functional Work Template

4.2.12.4.6 Operations
See Appendix B Tier 3 Constellation Functional Work Template

4.2.12.4.7 In-Space Contract End Item Systems
See Appendix B Tier 3 Constellation Functional Work Template

4.2.12.4.8 In-Space Systems Contract End Item

4.2.13 Robotic Mission Systems

Robotic Precursor Systems (RPS) include a range of robotic missions directly supporting human exploration. The purpose of the RPS missions includes characterizing Exploration destinations, validating key technologies supporting exploration, and preparing for and supporting future human missions. Robotic Precursor Systems include Orbiters and Landers and the associated subsystems necessary to accomplish the specific mission.

4.2.13.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.2.13.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.2.13.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.2.13.4 Reserved

4.2.13.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.2.13.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.2.13.7 Robotic Precursor Contract End Item Systems

See Appendix B Tier 3 Constellation Functional Work Template

4.2.13.8 Lunar Reconnaissance Orbiter

This element encompasses all the work (data, products, and services) required to develop, deliver, and operate a lunar mapping reconnaissance orbiter. It includes the spacecraft, payload, launch vehicle, mission operation, ground system, and the management, systems engineering, and mission assurance elements necessary for successfully delivering the lunar topographic and resource data products.

4.2.13.9 Lunar Robotic Lander

This element encompasses all the work (data, products and services) required to develop, deliver, and operate a robotic lander on the surface of the moon. It includes the spacecraft, payload, launch vehicle, mission operation, ground system and the management, systems engineering, and mission assurance elements necessary for successfully delivering the lunar surface resource verification products

4.2.14 Cargo Module

TBD

4.2.14.1 Cargo Module Management Team
SEE APPENDIX B

4.2.14.2 RFP/SEB Support
SEE APPENDIX B

4.2.14.3 Cargo Module IPT Support
SEE APPENDIX B

4.2.14.4 Cargo Module Prime Contractors
SEE APPENDIX B

4.2.14.4.1 System Management
See Appendix B

4.2.14.4.2 Systems Engineering
See Appendix B

4.2.14.4.3 Safety and Mission Assurance
See Appendix B

4.2.14.4.4 Reserved
See Appendix B

4.2.14.4.5 Integration and Test
See Appendix B

4.2.14.4.6 Operations
See Appendix B

4.2.14.4.7 Cargo Module Contract End Item Systems
See Appendix B

4.2.14.4.8 Cargo Module Contract End Item

4.2.15 Cargo Launch Vehicle
TBD

4.2.15.1 Cargo Launch Vehicle Management Team
SEE APPENDIX B

4.2.15.2 RFP/SEB Support
SEE APPENDIX B

4.2.15.3 Cargo Launch Vehicle IPT Support
SEE APPENDIX B

4.2.15.4 Cargo Launch Vehicle Prime Contractors
SEE APPENDIX B

4.2.15.4.1 System Management
See Appendix B

4.2.15.4.2 Systems Engineering
See Appendix B

4.2.15.4.3 Safety and Mission Assurance
See Appendix B

4.2.15.4.4 Reserved
See Appendix B

4.2.15.4.5 Integration and Test
See Appendix B

4.2.15.4.6 Operations
See Appendix B

4.2.15.4.7 Cargo Launch Vehicle Contract End ItemSystems
See Appendix B

4.2.15.4.8 Cargo Launch Vehicle Contract End Item

4.2.16 Surface Systems
TBD

4.2.16.1 Surface Systems Management Team
SEE APPENDIX B

4.2.16.2 RFP/SEB Support
SEE APPENDIX B

4.2.16.3 Surface Systems IPT Support
SEE APPENDIX B

4.2.16.4 Surface Systems Prime Contractors
SEE APPENDIX B

4.2.16.4.1 System Management

See Appendix B

4.2.16.4.2 Systems Engineering

See Appendix B

4.2.16.4.3 Safety and Mission Assurance

See Appendix B

4.2.16.4.4 Reserved

See Appendix B

4.2.16.4.5 Integration and Test

See Appendix B

4.2.16.4.6 Operations

See Appendix B

4.2.16.4.7 Surface Systems Contract End Item Systems

See Appendix B

4.2.16.4.8 Surface Systems Contract End Item

4.2.17 Ascent/Descent Systems

As applied to Lunar Missions, Systems required to transport crew and cargo from the destination orbit to the destination surface.

4.2.17.1 Ascent/Descent Systems Management Team

SEE APPENDIX B

4.2.17.2 RFP/SEB Support

SEE APPENDIX B

4.2.17.3 Ascent/Descent Systems IPT Support

SEE APPENDIX B

4.2.17.4 Ascent/Descent Systems Prime Contractors

SEE APPENDIX B

4.2.17.4.1 System Management

See Appendix B

4.2.17.4.2 Systems Engineering

See Appendix B

4.2.17.4.3 Safety and Mission Assurance

See Appendix B

4.2.17.4.4 Reserved

See Appendix B

4.2.17.4.5 Integration and Test

See Appendix B

4.2.17.4.6 Operations

See Appendix B

4.2.17.4.7 Ascent/Descent CEI Systems Contract End Item Systems

See Appendix B

4.2.17.4.8 Contract End Item 1

SEE APPENDIX B

4.3 System of Systems III

Details of all elements in Sections 4.3.1 through 4.3.6 can be found in Appendix A of this document.

4.3.1 System Management

See Appendix A

4.3.1.1 Program/Project Management

See Appendix A

4.3.1.2 Business Management

See Appendix A

4.3.1.3 Information Management

See Appendix A

4.3.1.4 Administrative

See Appendix A

4.3.1.5 Requirements Management

See Appendix A

4.3.1.6 Acquisition Management

See Appendix A

4.3.1.7 Comprehensive Risk Management

See Appendix A

4.3.1.8 Supportability and Integrated Logistics Support Management

See Appendix A

4.3.2 System of Systems Engineering

See Appendix A

4.3.2.1 Engineering Management

See Appendix A

4.3.2.2 Requirements Definition

See Appendix A

4.3.2.3 Configuration and Data Management

See Appendix A

4.3.2.4 Risk Identification and Analysis
See Appendix A

4.3.2.5 System Definition
See Appendix A

4.3.2.6 System Integration
See Appendix A

4.3.2.7 Integrated Logistics Support
See Appendix A

4.3.2.8 Inter Discipline Team (IDT) Activity
See Appendix A

4.3.3 Safety and Mission Assurance
See Appendix A

4.3.3.1 Management and Administration
See Appendix A

4.3.3.1.1 Business Management
See Appendix A

4.3.3.2 Safety and Mission Assurance (S&MA) Integration
See Appendix A

4.3.3.2.1 External Assessment
See Appendix A

4.3.3.3 Safety and Mission Assurance Panels
See Appendix A

4.3.3.3.1 RMS Review Panels
See Appendix A

4.3.3.4 Safety, Health and Environment Assurance (SHEA)
See Appendix A

4.3.3.4.1 Occupational (Industrial) Safety
See Appendix A

4.3.3.4.2 Occupational Health
See Appendix A

4.3.3.4.3 Environmental Protection

See Appendix A

4.3.3.5 Reliability and Maintainability

See Appendix A

4.3.3.5.1 Reliability

See Appendix A

4.3.3.5.2 Maintainability

See Appendix A

4.3.3.6 Product Assurance

See Appendix A

4.3.3.6.1 Electrical, Electronic, Electromechanical (EEE) Parts

See Appendix A

4.3.3.6.2 Materials and Processes Product Assurance

See Appendix A

4.3.3.7 Software Assurance

See Appendix A

4.3.3.8 Operations Safety and Mission Assurance (S&MA)

See Appendix A

4.3.3.9 Human Rating and Crew Survival

See Appendix A

4.3.3.10 Nuclear Safety

See Appendix A

4.3.4 Advanced Development

See Appendix A

4.3.4.1 Technology Integration

See Appendix A

4.3.5 Integration and Test

See Appendix A

4.3.5.1 Analysis and Design

See Appendix A

4.3.5.2 Test

See Appendix A

4.3.5.3 Assembly

See Appendix A

4.3.6 Integrated Operations

See Appendix A

4.3.6.1 Operations Management

See Appendix A

4.3.6.2 Operations Integration

See Appendix A

4.3.6.2.1 Ground Operations Integration

See Appendix A

4.3.6.2.2 Mission Operations Integration

See Appendix A

4.3.6.2.3 Surface Operations Integration

See Appendix A

4.3.6.3 Consolidated Systems Operations

See Appendix A

4.3.6.3.1 Mission Integration

See Appendix A

4.3.6.3.2 Ground Processing

See Appendix A

4.3.6.3.3 Mission Operations

See Appendix A

4.3.6.3.4 Surface Operations

See Appendix A

4.3.6.3.5 Communications

See Appendix A

4.3.7 Ground Systems

This effort includes development and operations of common and multi-use facilities /systems such as a mission control center, communication networks, pre-launch ground processing infrastructure, etc. supporting human exploration and supporting Crew missions as well as robotic precursor missions. This element includes all common and multi-use facilities/systems that do not fly as part of a mission in the support of Mission Operations and pre-launch processing operations. The complex of equipment, HW, SW, and facilities/systems required to assemble, integrate, Testing, and monitor the Exploration Missions systems during pre-launch processing, launch simulations, flight simulations, rehearsals, launch operations, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include spacecraft and instrument Testing beds, post-launch flight SW development equipment, or interfaces to such capability. This element also includes all required unique support systems to Testing, process, certify, operate, and maintain the common ground systems.

4.3.7.1 Ground Systems Management Team

See Appendix A.

4.3.7.2 RFP/SEB Support

4.3.7.3 Ground Systems IPT Support

See Appendix A.

4.3.7.3.1 Systems Engineering & Integration

See Appendix A.

4.3.7.3.2 Constellation Systems Analysis

See Appendix A.

4.3.7.3.3 Cost Engineering

See Appendix A.

4.3.7.3.4 Safety & Mission Assurance

See Appendix A.

4.3.7.3.5 Operations

See Appendix A.

4.3.7.3.6 Human Centered

See Appendix A.

4.3.7.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix A.

4.3.7.3.8 Command, Control & Communications

See Appendix A.

4.3.7.3.9 Ground Infrastructure

See Appendix A.

4.3.7.3.10 Aerosciences & Flight Mechanics

See Appendix A.

4.3.7.3.11 Propulsion & Fluids

See Appendix A.

4.3.7.3.12 Power Systems

See Appendix A.

4.3.7.3.13 Computer, Software, Automation

See Appendix A.

4.3.7.3.14 Robotics

See Appendix A.

4.3.7.4 Ground Systems Contract End Item (CEI) Prime Contractor

4.3.7.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.3.7.4.2 System Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.3.7.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.3.7.4.4 Reserved

4.3.7.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.3.7.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.3.7.5 Ground Processing Facilities and Systems

For the given SS spiral, this element captures the effort required to implement the common, multi-use facilities, systems and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor and launch the given system, including integrated test, with other Spiral I systems. These activities include work necessary to

design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the ground processing facilities and systems.

4.3.7.6 Launch Facilities and Systems

This element encompasses the effort required to implement the common, multi-use facilities, systems, and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor, and launch the Spiral I launch vehicle. These activities include work necessary to design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the launch facilities and systems.

4.3.7.7 Mission Control Facilities and Systems

This element provides the infrastructure necessary for the overall command and control authority for the SS missions. The capabilities required include voice and video communications, telemetry reception, and data and command uplink to the SS spacecraft elements. In addition to these basic capabilities, the facility will host the necessary software tools and applications necessary to support operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc), and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc). As the SS elements are further defined, it is anticipated that additional capabilities will be incorporated into the mission control facility.

4.3.7.7.1 System of Systems Command

This element provides for the development and sustaining of all necessary software applications, and associated hardware, to support command loads builds - either discrete commands or software loads, verification of the correct content, transmission to and verification that the command was correctly received from the desired SS element, and reception of positive feedback from the SS element that the commands have been successfully executed. This element also provides for the development and sustaining of the processes and tools necessary to accomplish the command reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.3.7.7.2 System of Systems Telemetry

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capability to receive, store and retrieve, process, and display the telemetry from the various SS elements. This element also provides for the development and sustaining of the processes and tools necessary for data telemetry reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.3.7.7.3 Voice and Video Communications

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capabilities for communications between the flight crew and the mission control facilities. This includes the transmission, reception, encryption, processing, and recorded storage and retrieval of communications information.

4.3.7.7.4 Mission Control Center (MCC)

This element covers the portion of the facility and systems to provide a central location for overall mission command and control. Within the Mission Control Center (MCC), this element provides for the development, sustaining, and hosting of the software tools and applications, and associated hardware, necessary to support missions operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc) tools, and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc).

4.3.7.7.5 Software Development and Sustainment

This element provides for the development and sustaining efforts required for all necessary software applications required by the mission control facilities and systems.

4.3.7.8 Training/Simulation Facilities and Systems

This element provides for the development and sustaining of the facilities and systems necessary to train and prepare ground operations personnel, flight controllers, and flight crew to perform their assigned tasks. The facilities and systems include flight simulators covering all facets of the mission, mockups, computer-based trainers (CBT), Part-Task Trainers (PTT), Flight Controller Trainers (FCT), and any other trainer as required by the Mission. This element will also address any necessary integration between one or more trainers/simulators and with the mission control facilities to support training between the flight control team and the flight crews, and to support various product verification tasks (e.g., procedure verification).

4.3.7.8.1 Ground Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Ground Operations personnel to perform the tasks required in the pre-flight processing of the SS elements, preparation leading up to launch operations, and rescue of the flight crew.

4.3.7.8.2 Flight Crew/Flight Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Flight Operations personnel to perform the tasks required in the pre-flight preparations for and eventual execution of an SS mission.

4.3.7.8.3 Surface Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Surface Operations personnel to perform

the tasks required in the pre-flight preparations for and eventual execution of SS surface operations.

4.3.7.9 Communications Facilities and Systems

This element describes the communications infrastructure that consists of an administrative segment, an operations segment, and a mission support segment. The administrative communication facility and systems include office telephones, office networks/data systems, paging & area warning, broadband communications distribution system, and the associated cable plant. The operational communication facilities and systems include the operational intercom system, operational television system, photo optic control system, timing and countdown system, wideband transmission systems, frequency division multiplex system, and any new or other communication facility and systems required but not yet identified. The mission support segment facilities and systems include the global networks that provide data, voice, and video communications among the government and contractor support sites to the mission.

4.3.8 Crew Exploration Vehicle (CEV)

The Crew Exploration Vehicle (CEV) is the spacecraft that provides transportation for the crew to and from space. The CEV does not include the launch vehicle required to boost the spacecraft into orbit. The CEV will initially operate in low-Earth orbit (LEO), and includes subsystems for functions such as crew survival during ascent, environmental control and life support, communications, navigation and control, power, thermal control, thermal protection, radiation protection, propulsion, docking, and recovery. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CEV as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.3.8.1 CEV Management Team

See Appendix B

4.3.8.2 RFP/SEB Support

See Appendix B

4.3.8.3 CEV IPT Support

SEE APPENDIX B

4.3.8.3.1 Systems Engineering & Integration

See Appendix B.

4.3.8.3.2 Constellation Systems Analysis

See Appendix B.

4.3.8.3.3 Cost Engineering

See Appendix B.

4.3.8.3.4 Safety & Mission Assurance

See Appendix B.

4.3.8.3.5 Operations

See Appendix B.

4.3.8.3.6 Human Centered

See Appendix B.

4.3.8.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.3.8.3.8 Command, Control & Communications

See Appendix B.

4.3.8.3.9 Ground Infrastructure

See Appendix B.

4.3.8.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.3.8.3.11 Propulsion & Fluids

See Appendix B.

4.3.8.3.12 Power Systems

See Appendix B.

4.3.8.3.13 Computer, Software & Automation

See Appendix B.

4.3.8.3.14 Robotics

See Appendix B.

4.3.8.4 CEV Prime Contractors

SEE APPENDIX B

4.3.8.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.3.8.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.3.8.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.3.8.4.4 Reserved

4.3.8.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.3.8.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.3.8.4.7 Crew Exploration Vehicle (CEV) Ground Systems

See Appendix B Tier 3 Constellation Functional Work Template.

4.3.8.4.8 Contract End Item(s)

To be provided by CEV management.

4.3.9 Crew Launch Vehicle (CLV)

The Crew Launch Vehicle (CLV) is the part of the human-rated launch system that delivers the CEV to LEO. The CLV includes the launch vehicle stages and subsystems such as tanks and plumbing, supporting structures, propulsion, controls, communications, and power. Also included is any CLV specific launch support infrastructure. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CLV, as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.3.9.1 Crew Launch Vehicle Management Team

SEE APPENDIX B

4.3.9.2 RFP/SEB Support

4.3.9.3 Crew Launch Vehicle IPT Support

SEE APPENDIX B

4.3.9.3.1 Systems Engineering & Integration

See Appendix B.

4.3.9.3.2 Constellation Systems Analysis

See Appendix B.

4.3.9.3.3 Cost Engineering

See Appendix B.

4.3.9.3.4 Safety & Mission Assurance

See Appendix B.

4.3.9.3.5 Operations

See Appendix B.

4.3.9.3.6 Human Centered

See Appendix B.

4.3.9.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.3.9.3.8 Command, Control & Communications

See Appendix B.

4.3.9.3.9 Ground Infrastructure

See Appendix B.

4.3.9.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.3.9.3.11 Propulsion & Fluids

See Appendix B.

4.3.9.3.12 Power Systems

See Appendix B.

4.3.9.3.13 Computer, Software & Automation

See Appendix B.

4.3.9.3.14 Robotics

See Appendix B.

4.3.9.4 Crew Launch Vehicle Prime Contractors

SEE APPENDIX B

4.3.9.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.3.9.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.3.9.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.3.9.4.4 Reserved

4.3.9.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.3.9.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.3.9.4.7 Crew Launch Vehicle Ground Systems

The work to develop unique HRLV ground systems for the given system of systems spiral.

4.3.9.4.8 Contract End Item

SEE APPENDIX B

4.3.10 In-Space Transportation Systems

TBD

4.3.10.1 In-Space Transportation Systems Management Team

SEE APPENDIX B

4.3.10.2 RFP/SEB Support

SEE APPENDIX B

4.3.10.3 In-Space Transportation Systems IPT Support

SEE APPENDIX B

4.3.10.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.3.10.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.3.10.3.3 Cost Engineering

SEE APPENDIX B

4.3.10.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.3.10.3.5 Operations

SEE APPENDIX B

4.3.10.3.6 Human Centered

SEE APPENDIX B

4.3.10.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.3.10.3.8 Command, Control & Communciations

SEE APPENDIX B

4.3.10.3.9 Ground Infrastructure

SEE APPENDIX B

4.3.10.3.10 Aerosciences & Flight Mechanics
SEE APPENDIX B

4.3.10.3.11 Propulsion & Fluids
SEE APPENDIX B

4.3.10.3.12 Power Systems
SEE APPENDIX B

4.3.10.3.13 Computer, Software, Automation
SEE APPENDIX B

4.3.10.3.14 Robotics
SEE APPENDIX B

4.3.10.4 In-Space Transportation Systems Prime Contractors
SEE APPENDIX B

4.3.10.4.1 System Management
See Appendix B

4.3.10.4.2 Systems Engineering
See Appendix B

4.3.10.4.3 Safety and Mission Assurance
See Appendix B

4.3.10.4.4 Reserved
See Appendix B

4.3.10.4.5 Integration and Test
See Appendix B

4.3.10.4.6 Operations
See Appendix B

4.3.10.4.7 In-Space Transportation Ground Systems
See Appendix B

4.3.10.4.8 In-Space Transportation CEI
See Appendix B

4.3.11 Human Support Systems
Human Support Systems (HSS) include systems and equipment that permit and facilitate crew operations in environments otherwise unsuitable for human activities. Examples of

HSS include extravehicular activity (EVA) suits and backpacks, maneuvering units, robot assistants, and special tools. HSS does not include equipment integrated into the crew exploration vehicle or other modules that permit servicing or recharging of the HSS. Each HSS may be developed as a single end item or multiple modules that constitute an end item. Typically, a system might include subsystems such as power, communications, and environmental control to permit the crew to operate autonomously from the primary vehicle. HSS also includes all design, development, production, assembly, and test efforts to deliver the completed and qualified system.

4.3.11.1 Human Support Systems Management Team

SEE APPENDIX B

4.3.11.2 RFP/SEB Support

SEE APPENDIX B

4.3.11.3 Human Support Systems IPT Support

SEE APPENDIX B

4.3.11.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.3.11.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.3.11.3.3 Cost Engineering

SEE APPENDIX B

4.3.11.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.3.11.3.5 Operations

SEE APPENDIX B

4.3.11.3.6 Human Centered

SEE APPENDIX B

4.3.11.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.3.11.3.8 Command, Control & Communciations

SEE APPENDIX B

4.3.11.3.9 Ground Infrastructure

SEE APPENDIX B

4.3.11.3.10 Aerosciences & Flight Mechanics

SEE APPENDIX B

4.3.11.3.11 Propulsion & Fluids

SEE APPENDIX B

4.3.11.3.12 Power Systems

SEE APPENDIX B

4.3.11.3.13 Computer, Software, Automation

SEE APPENDIX B

4.3.11.3.14 Robotics

SEE APPENDIX B

4.3.11.4 Human Support Systems Prime Contractors

SEE APPENDIX B

4.3.11.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.3.11.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.3.11.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.3.11.4.4 Reserved

4.3.11.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.3.11.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.3.11.4.7 Human Support Ground Systems

See Appendix B Tier 3 Constellation Functional Work Template

4.3.11.4.8 EVA System

This element includes the work required to develop systems for all extravehicular activity during Exploration missions. This effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility aids. For the given SS spiral, the work to develop the systems is required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

4.3.12 In-Space Systems

In-Space Systems (InSS) includes spacecraft supporting both human and robotic exploration of the Moon, Mars, and other solar system bodies. This element can include logistics modules carrying fuel and supplies; spacecraft positioned to support communication, navigation, and/or reconnaissance requirements; and rendezvous/docking and robotic vehicles to support assembly in space. In-Space Systems will typically be free-flying spacecraft and include the subsystems to provide communications, command, and control, power, thermal control, and propulsion for orbit maintenance, maneuvering, and docking. In-Space Systems will also include all modifications/additions to the unique ground based communications assets(such as the Deep Space Network) to provide communications and navigation functions for human and robotic exploration. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified InSS, as well as the necessary unique support equipment to test, process, certify, transport, and operate the InSS..

4.3.12.1 In-Space Systems Management Team

SEE APPENDIX B

4.3.12.2 RFP/SEB Support

SEE APPENDIX B

4.3.12.3 In-Space Systems IPT Support

SEE APPENDIX B

4.3.12.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.3.12.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.3.12.3.3 Cost Engineering

SEE APPENDIX B

4.3.12.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.3.12.3.5 Operations

SEE APPENDIX B

4.3.12.3.6 Human Centered

SEE APPENDIX B

4.3.12.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.3.12.3.8 Command, Control & Communications
SEE APPENDIX B

4.3.12.3.9 Ground Infrastructure
SEE APPENDIX B

4.3.12.3.10 Aerosciences & Flight Mechanics
SEE APPENDIX B

4.3.12.3.11 Propulsion & Fluids
SEE APPENDIX B

4.3.12.3.12 Power Systems
SEE APPENDIX B

4.3.12.3.13 Computer, Software, Automation
SEE APPENDIX B

4.3.12.3.14 Robotics
SEE APPENDIX B

4.3.12.4 In-Space Systems Prime Contractor
SEE APPENDIX B

4.3.12.4.1 System Management
See Appendix B Tier 3 Constellation Functional Work Template

4.3.12.4.2 Systems Engineering
See Appendix B Tier 3 Constellation Functional Work Template

4.3.12.4.3 Safety and Mission Assurance
See Appendix B Tier 3 Constellation Functional Work Template

4.3.12.4.4 Reserved

4.3.12.4.5 Integration and Test
See Appendix B Tier 3 Constellation Functional Work Template

4.3.12.4.6 Operations
See Appendix B Tier 3 Constellation Functional Work Template

4.3.12.4.7 In-Space Contract End Item Systems
See Appendix B Tier 3 Constellation Functional Work Template

4.3.12.4.8 Contact End Item

4.3.13 Robotic Mission Systems

Robotic Precursor Systems (RPS) include a range of robotic missions directly supporting human exploration. The purpose of the RPS missions includes characterizing Exploration destinations, validating key technologies supporting exploration, and preparing for and supporting future human missions. Robotic Precursor Systems include Orbiters and Landers and the associated subsystems necessary to accomplish the specific mission.

4.3.13.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.3.13.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.3.13.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.3.13.4 Reserved

4.3.13.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.3.13.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.3.13.7 Robotic Precursor Contract End Item Systems

See Appendix B Tier 3 Constellation Functional Work Template

4.3.13.8 Lunar Reconnaissance Orbiter

This element encompasses all the work (data, products, and services) required to develop, deliver, and operate a lunar mapping reconnaissance orbiter. It includes the spacecraft, payload, launch vehicle, mission operation, ground system, and the management, systems engineering, and mission assurance elements necessary for successfully delivering the lunar topographic and resource data products.

4.3.13.9 Lunar Robotic Lander

This element encompasses all the work (data, products and services) required to develop, deliver, and operate a robotic lander on the surface of the moon. It includes the spacecraft, payload, launch vehicle, mission operation, ground system and the management, systems engineering, and mission assurance elements necessary for successfully delivering the lunar surface resource verification products

4.3.14 Cargo Module

SEE APPENDIX B

4.3.14.1 Cargo Module Management Team
SEE APPENDIX B

4.3.14.2 RFP/SEB Support
SEE APPENDIX B

4.3.14.3 Cargo Module IPT Support
SEE APPENDIX B

4.3.14.4 Cargo Module Prime Contractors
SEE APPENDIX B

4.3.14.4.1 System Management
See Appendix B

4.3.14.4.2 Systems Engineering
See Appendix B

4.3.14.4.3 Safety and Mission Assurance
See Appendix B

4.3.14.4.4 Reserved
See Appendix B

4.3.14.4.5 Integration and Test
See Appendix B

4.3.14.4.6 Operations
See Appendix B

4.3.14.4.7 Cargo Module Contract End Item Systems
See Appendix B

4.3.14.4.8 Cargo Module Contract End Item

4.3.15 Cargo Launch Vehicle
SEE APPENDIX B

4.3.15.1 Cargo Launch Vehicle Management Team
SEE APPENDIX B

4.3.15.2 RFP/SEB Support
SEE APPENDIX B

4.3.15.3 Cargo Launch Vehicle IPT Support
SEE APPENDIX B

4.3.15.4 Cargo Launch Vehicle Prime Contractors
SEE APPENDIX B

4.3.15.4.1 System Management
See Appendix B

4.3.15.4.2 Systems Engineering
See Appendix B

4.3.15.4.3 Safety and Mission Assurance
See Appendix B

4.3.15.4.4 Reserved
See Appendix B

4.3.15.4.5 Integration and Test
See Appendix B

4.3.15.4.6 Operations
See Appendix B

4.3.15.4.7 Cargo Launch Vehicle Contract End Item Systems
See Appendix B

4.3.15.4.8 Cargo Launch Vehicle Contract End Item

4.3.16 Surface Systems
SEE APPENDIX B

4.3.16.1 Surface Systems Management Team
SEE APPENDIX B

4.3.16.2 RFP/SEB Support
SEE APPENDIX B

4.3.16.3 Surface Systems IPT Support
SEE APPENDIX B

4.3.16.4 Surface Systems Prime Contractors
SEE APPENDIX B

4.3.16.4.1 System Management

See Appendix B

4.3.16.4.2 Systems Engineering

See Appendix B

4.3.16.4.3 Safety and Mission Assurance

See Appendix B

4.3.16.4.4 Reserved

See Appendix B

4.3.16.4.5 Integration and Test

See Appendix B

4.3.16.4.6 Operations

See Appendix B

4.3.16.4.7 Surface Systems Contract End Item Systems

See Appendix B

4.3.16.4.8 Surface Systems Contract End Item

4.3.17 Ascent/Descent Systems

As applied to Lunar Missions, Systems required to transport crew and cargo from the destination orbit to the destination surface.

4.3.17.1 Ascent/Descent Systems Management Team

SEE APPENDIX B

4.3.17.2 RFP/SEB Support

SEE APPENDIX B

4.3.17.3 Ascent/Descent Systems IPT Support

SEE APPENDIX B

4.3.17.4 Ascent/Descent Systems Prime Contractors

SEE APPENDIX B

4.3.17.4.1 System Management

See Appendix B

4.3.17.4.2 Systems Engineering

See Appendix B

4.3.17.4.3 Safety and Mission Assurance

See Appendix B

4.3.17.4.4 Reserved

See Appendix B

4.3.17.4.5 Integration and Test

See Appendix B

4.3.17.4.6 Operations

See Appendix B

4.3.17.4.7 Ascent/Descent CEI Systems Contract End Item Systems

See Appendix B

4.3.17.4.8 Contract End Item 1

SEE APPENDIX B

4.n System of Systems (n)

Details of all elements in Sections 4.n.1 through 4.n.6 can be found in Appendix A of this document.

4.n.1 System Management

See Appendix A

4.n.1.1 Program/Project Management

See Appendix A

4.n.1.2 Business Management

See Appendix A

4.n.1.3 Information Management

See Appendix A

4.n.1.4 Administrative

See Appendix A

4.n.1.5 Requirements Management

See Appendix A

4.n.1.6 Acquisition Management

See Appendix A

4.n.1.7 Comprehensive Risk Management

See Appendix A

4.n.1.8 Supportability and Integrated Logistics Support Management

See Appendix A

4.n.2 System of Systems Engineering

See Appendix A

4.n.2.1 Engineering Management

See Appendix A

4.n.2.2 Requirements Definition

See Appendix A

4.n.2.3 Configuration and Data Management

See Appendix A

4.n.2.4 Risk Identification and Analysis
See Appendix A

4.n.2.5 System Definition
See Appendix A

4.n.2.6 System Integration
See Appendix A

4.n.2.7 Integrated Logistics Support
See Appendix A

4.n.2.8 Inter Discipline Team (IDT) Activity
See Appendix A

4.n.3 Safety and Mission Assurance
See Appendix A

4.n.3.1 Management and Administration
See Appendix A

4.n.3.1.1 Business Management
See Appendix A

4.n.3.2 Safety and Mission Assurance (S&MA) Integration
See Appendix A

4.n.3.2.1 External Assessment
See Appendix A

4.n.3.3 Safety and Mission Assurance Panels
See Appendix A

4.n.3.3.1 RMS Review Panels
See Appendix A

4.n.3.4 Safety, Health and Environment Assurance (SHEA)
See Appendix A

4.n.3.4.1 Occupational (Industrial) Safety
See Appendix A

4.n.3.4.2 Occupational Health
See Appendix A

4.n.3.4.3 Environmental Protection

See Appendix A

4.n.3.5 Reliability and Maintainability

See Appendix A

4.n.3.5.1 Reliability

See Appendix A

4.n.3.5.2 Maintainability

See Appendix A

4.n.3.6 Product Assurance

See Appendix A

4.n.3.6.1 Electrical, Electronic, Electromechanical (EEE) Parts

See Appendix A

4.n.3.6.2 Materials and Processes Product Assurance

See Appendix A

4.n.3.7 Software Assurance

See Appendix A

4.n.3.8 Operations Safety and Mission Assurance (S&MA)

See Appendix A

4.n.3.9 Human Rating and Crew Survival

See Appendix A

4.n.3.10 Nuclear Safety

See Appendix A

4.n.4 Advanced Development

See Appendix A

4.n.4.1 Technology Integration

See Appendix A

4.n.5 Integration and Test

See Appendix A

4.n.5.1 Analysis and Design

See Appendix A

4.n.5.2 Test

See Appendix A

4.n.5.3 Assembly

See Appendix A

4.n.6 Integrated Operations

See Appendix A

4.n.6.1 Operations Management

See Appendix A

4.n.6.2 Operations Integration

See Appendix A

4.n.6.2.1 Ground Operations Integration

See Appendix A

4.n.6.2.2 Mission Operations Integration

See Appendix A

4.n.6.2.3 Surface Operations Integration

See Appendix A

4.n.6.3 Consolidated Systems Operations

See Appendix A

4.n.6.3.1 Mission Integration

See Appendix A

4.n.6.3.2 Ground Processing

See Appendix A

4.n.6.3.3 Mission Operations

See Appendix A

4.n.6.3.4 Surface Operations

See Appendix A

4.n.6.3.5 Communications

See Appendix A

4.n.7 Ground Systems

This effort includes development and operations of common and multi-use facilities /systems such as a mission control center, communication networks, pre-launch ground processing infrastructure, etc. supporting human exploration and supporting Crew missions as well as robotic precursor missions. This element includes all common and multi-use facilities/systems that do not fly as part of a mission in the support of Mission Operations and pre-launch processing operations. The complex of equipment, HW, SW, and facilities/systems required to assemble, integrate, Testing, and monitor the Exploration Missions systems during pre-launch processing, launch simulations, flight simulations, rehearsals, launch operations, and flight operations and the support necessary to operate and maintain it. Includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the mission operations system SW. May include spacecraft and instrument Testing beds, post-launch flight SW development equipment, or interfaces to such capability. This element also includes all required unique support systems to Testing, process, certify, operate, and maintain the common ground systems.

4.n.7.1 Ground Systems Management Team

See Appendix A.

4.n.7.2 RFP/SEB Support

4.n.7.3 Ground Systems IPT Support

See Appendix A.

4.n.7.3.1 Systems Engineering & Integration

See Appendix A.

4.n.7.3.2 Constellation Systems Analysis

See Appendix A.

4.n.7.3.3 Cost Engineering

See Appendix A.

4.n.7.3.4 Safety & Mission Assurance

See Appendix A.

4.n.7.3.5 Operations

See Appendix A.

4.n.7.3.6 Human Centered

See Appendix A.

4.n.7.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix A.

4.n.7.3.8 Command, Control & Communications

See Appendix A.

4.n.7.3.9 Ground Infrastructure

See Appendix A.

4.n.7.3.10 Aerosciences & Flight Mechanics

See Appendix A.

4.n.7.3.11 Propulsion & Fluids

See Appendix A.

4.n.7.3.12 Power Systems

See Appendix A.

4.n.7.3.13 Computer, Software, Automation

See Appendix A.

4.n.7.3.14 Robotics

See Appendix A.

4.n.7.4 Ground Systems Contract End Item (CEI) Prime Contractor

4.n.7.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.n.7.4.2 System Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.n.7.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.n.7.4.4 Reserved

4.n.7.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.n.7.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.n.7.5 Ground Processing Facilities and Systems

For the given SS spiral, this element captures the effort required to implement the common, multi-use facilities, systems and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor and launch the given system, including integrated test, with other Spiral I systems. These activities include work necessary to

design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the ground processing facilities and systems.

4.n.7.6 Launch Facilities and Systems

This element encompasses the effort required to implement the common, multi-use facilities, systems, and equipment, including software, necessary to receive, inspect, assemble, integrate, test, monitor, and launch the Spiral I launch vehicle. These activities include work necessary to design and analyze, acquire, manufacture/produce, construct/modify, assemble, test, and activate these facilities, systems, and equipment. This element also captures the activities to operate, maintain, retire, and dispose of the launch facilities and systems.

4.n.7.7 Mission Control Facilities and Systems

This element provides the infrastructure necessary for the overall command and control authority for the SS missions. The capabilities required include voice and video communications, telemetry reception, and data and command uplink to the SS spacecraft elements. In addition to these basic capabilities, the facility will host the necessary software tools and applications necessary to support operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc), and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc). As the SS elements are further defined, it is anticipated that additional capabilities will be incorporated into the mission control facility.

4.n.7.7.1 System of Systems Command

This element provides for the development and sustaining of all necessary software applications, and associated hardware, to support command loads builds - either discrete commands or software loads, verification of the correct content, transmission to and verification that the command was correctly received from the desired SS element, and reception of positive feedback from the SS element that the commands have been successfully executed. This element also provides for the development and sustaining of the processes and tools necessary to accomplish the command reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.n.7.7.2 System of Systems Telemetry

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capability to receive, store and retrieve, process, and display the telemetry from the various SS elements. This element also provides for the development and sustaining of the processes and tools necessary for data telemetry reconfigurable product builds, deliveries, and incorporation into the mission control facilities.

4.n.7.7.3 Voice and Video Communications

This element provides for the development and sustaining of all necessary software applications, and associated hardware, for the capabilities for communications between the flight crew and the mission control facilities. This includes the transmission, reception, encryption, processing, and recorded storage and retrieval of communications information.

4.n.7.7.4 Mission Control Center (MCC)

This element covers the portion of the facility and systems to provide a central location for overall mission command and control. Within the Mission Control Center (MCC), this element provides for the development, sustaining, and hosting of the software tools and applications, and associated hardware, necessary to support missions operations, including data analysis tools, trajectory planning, on-board resource allocation verification (O2, power, thermal, water, etc) tools, and crew activity planning. This element also addresses the necessary interoperability of the control center facilities with other control centers (share communications, telemetry, command, etc).

4.n.7.7.5 Software Development and Sustainment

This element provides for the development and sustaining efforts required for all necessary software applications required by the mission control facilities and systems.

4.n.7.8 Training/Simulation Facilities and Systems

This element provides for the development and sustaining of the facilities and systems necessary to train and prepare ground operations personnel, flight controllers, and flight crew to perform their assigned tasks. The facilities and systems include flight simulators covering all facets of the mission, mockups, computer-based trainers (CBT), Part-Task Trainers (PTT), Flight Controller Trainers (FCT), and any other trainer as required by the Mission. This element will also address any necessary integration between one or more trainers/simulators and with the mission control facilities to support training between the flight control team and the flight crews, and to support various product verification tasks (e.g., procedure verification).

4.n.7.8.1 Ground Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Ground Operations personnel to perform the tasks required in the pre-flight processing of the SS elements, preparation leading up to launch operations, and rescue of the flight crew.

4.n.7.8.2 Flight Crew/Flight Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Flight Operations personnel to perform the tasks required in the pre-flight preparations for and eventual execution of an SS mission.

4.n.7.8.3 Surface Operations Trainer/Simulators

This element provides the trainers/simulators necessary to provide the required experience and training for the Flight Crew and Surface Operations personnel to perform

the tasks required in the pre-flight preparations for and eventual execution of SS surface operations.

4.n.7.9 Communications Facilities and Systems

This element describes the communications infrastructure that consists of an administrative segment, an operations segment, and a mission support segment. The administrative communication facility and systems include office telephones, office networks/data systems, paging & area warning, broadband communications distribution system, and the associated cable plant. The operational communication facilities and systems include the operational intercom system, operational television system, photo optic control system, timing and countdown system, wideband transmission systems, frequency division multiplex system, and any new or other communication facility and systems required but not yet identified. The mission support segment facilities and systems include the global networks that provide data, voice, and video communications among the government and contractor support sites to the mission.

4.n.8 Crew Exploration Vehicle (CEV)

The Crew Exploration Vehicle (CEV) is the spacecraft that provides transportation for the crew to and from space. The CEV does not include the launch vehicle required to boost the spacecraft into orbit. The CEV will initially operate in low-Earth orbit (LEO), and includes subsystems for functions such as crew survival during ascent, environmental control and life support, communications, navigation and control, power, thermal control, thermal protection, radiation protection, propulsion, docking, and recovery. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CEV as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.n.8.1 CEV Management Team

See Appendix B

4.n.8.2 RFP/SEB Support

See Appendix B

4.n.8.3 CEV IPT Support

SEE APPENDIX B

4.n.8.3.1 Systems Engineering & Integration

See Appendix B.

4.n.8.3.2 Constellation Systems Analysis

See Appendix B.

4.n.8.3.3 Cost Engineering

See Appendix B.

4.n.8.3.4 Safety & Mission Assurance

See Appendix B.

4.n.8.3.5 Operations

See Appendix B.

4.n.8.3.6 Human Centered

See Appendix B.

4.n.8.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.n.8.3.8 Command, Control & Communications

See Appendix B.

4.n.8.3.9 Ground Infrastructure

See Appendix B.

4.n.8.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.n.8.3.11 Propulsion & Fluids

See Appendix B.

4.n.8.3.12 Power Systems

See Appendix B.

4.n.8.3.13 Computer, Software & Automation

See Appendix B.

4.n.8.3.14 Robotics

See Appendix B.

4.n.8.4 CEV Prime Contractors

SEE APPENDIX B

4.n.8.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.n.8.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.n.8.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.n.8.4.4 Reserved

4.n.8.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.n.8.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.n.8.4.7 Crew Exploration Vehicle (CEV) Ground Systems

See Appendix B Tier 3 Constellation Functional Work Template.

4.n.8.4.8 Contract End Item(s)

To be provided by CEV management.

4.n.9 Crew Launch Vehicle (CLV)

The Crew Launch Vehicle (CLV) is the part of the human-rated launch system that delivers the CEV to LEO. The CLV includes the launch vehicle stages and subsystems such as tanks and plumbing, supporting structures, propulsion, controls, communications, and power. Also included is any CLV specific launch support infrastructure. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified CLV, as well as the necessary unique support equipment to test, process, certify, transport, and operate the vehicle.

4.n.9.1 Crew Launch Vehicle Management Team

SEE APPENDIX B

4.n.9.2 RFP/SEB Support

4.n.9.3 Crew Launch Vehicle IPT Support

SEE APPENDIX B

4.n.9.3.1 Systems Engineering & Integration

See Appendix B.

4.n.9.3.2 Constellation Systems Analysis

See Appendix B.

4.n.9.3.3 Cost Engineering

See Appendix B.

4.n.9.3.4 Safety & Mission Assurance

See Appendix B.

4.n.9.3.5 Operations

See Appendix B.

4.n.9.3.6 Human Centered

See Appendix B.

4.n.9.3.7 Structural, Mechanical, Materials & Manufacturing

See Appendix B.

4.n.9.3.8 Command, Control & Communications

See Appendix B.

4.n.9.3.9 Ground Infrastructure

See Appendix B.

4.n.9.3.10 Aerosciences & Flight Mechanics

See Appendix B.

4.n.9.3.11 Propulsion & Fluids

See Appendix B.

4.n.9.3.12 Power Systems

See Appendix B.

4.n.9.3.13 Computer, Software & Automation

See Appendix B.

4.n.9.3.14 Robotics

See Appendix B.

4.n.9.4 Crew Launch Vehicle Prime Contractors

SEE APPENDIX B

4.n.9.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.n.9.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.n.9.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.n.9.4.4 Reserved

4.n.9.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.n.9.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.n.9.4.7 Crew Launch Vehicle Ground Systems

The work to develop unique HRLV ground systems for the given system of systems spiral.

4.n.9.4.8 Launch Vehicle Contract End Item

SEE APPENDIX B

4.n.10 In-Space Transportation Systems

TBD

4.n.10.1 In-Space Transportation Systems Management Team

SEE APPENDIX B

4.n.10.2 RFP/SEB Support

SEE APPENDIX B

4.n.10.3 In-Space Transportation Systems IPT Support

SEE APPENDIX B

4.n.10.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.n.10.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.n.10.3.3 Cost Engineering

SEE APPENDIX B

4.n.10.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.n.10.3.5 Operations

SEE APPENDIX B

4.n.10.3.6 Human Centered

SEE APPENDIX B

4.n.10.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.n.10.3.8 Command, Control & Communciations

SEE APPENDIX B

4.n.10.3.9 Ground Infrastructure

SEE APPENDIX B

4.n.10.3.10 Aerosciences & Flight Mechanics
SEE APPENDIX B

4.n.10.3.11 Propulsion & Fluids
SEE APPENDIX B

4.n.10.3.12 Power Systems
SEE APPENDIX B

4.n.10.3.13 Computer, Software, Automation
SEE APPENDIX B

4.n.10.3.14 Robotics
SEE APPENDIX B

4.n.10.4 In-Space Transportation Systems Prime Contractors
SEE APPENDIX B

4.n.10.4.1 System Management
See Appendix B

4.n.10.4.2 Systems Engineering
See Appendix B

4.n.10.4.3 Safety and Mission Assurance
See Appendix B

4.n.10.4.4 Reserved
See Appendix B

4.n.10.4.5 Integration and Test
See Appendix B

4.n.10.4.6 Operations
See Appendix B

4.n.10.4.7 In-Space Transportation Ground Systems
See Appendix B

4.n.10.4.8 In-Space Transportation CEI
See Appendix B

4.n.11 Human Support Systems
Human Support Systems (HSS) include systems and equipment that permit and facilitate crew operations in environments otherwise unsuitable for human activities. Examples of

HSS include extravehicular activity (EVA) suits and backpacks, maneuvering units, robot assistants, and special tools. HSS does not include equipment integrated into the crew exploration vehicle or other modules that permit servicing or recharging of the HSS. Each HSS may be developed as a single end item or multiple modules that constitute an end item. Typically, a system might include subsystems such as power, communications, and environmental control to permit the crew to operate autonomously from the primary vehicle. HSS also includes all design, development, production, assembly, and test efforts to deliver the completed and qualified system.

4.n.11.1 Human Support Systems Management Team

SEE APPENDIX B

4.n.11.2 RFP/SEB Support

SEE APPENDIX B

4.n.11.3 Human Support Systems IPT Support

SEE APPENDIX B

4.n.11.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.n.11.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.n.11.3.3 Cost Engineering

SEE APPENDIX B

4.n.11.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.n.11.3.5 Operations

SEE APPENDIX B

4.n.11.3.6 Human Centered

SEE APPENDIX B

4.n.11.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.n.11.3.8 Command, Control & Communciations

SEE APPENDIX B

4.n.11.3.9 Ground Infrastructure

SEE APPENDIX B

4.n.11.3.10 Aerosciences & Flight Mechanics

SEE APPENDIX B

4.n.11.3.11 Propulsion & Fluids

SEE APPENDIX B

4.n.11.3.12 Power Systems

SEE APPENDIX B

4.n.11.3.13 Computer, Software, Automation

SEE APPENDIX B

4.n.11.3.14 Robotics

SEE APPENDIX B

4.n.11.4 Human Support Systems Prime Contractors

SEE APPENDIX B

4.n.11.4.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.n.11.4.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.n.11.4.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.n.11.4.4 Reserved

4.n.11.4.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.n.11.4.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.n.11.4.7 Human Support Ground Systems

See Appendix B Tier 3 Constellation Functional Work Template

4.n.11.4.8 EVA System

This element includes the work required to develop systems for all extravehicular activity during Exploration missions. This effort includes delivery and operation of space suit systems, airlock systems, and in-space EVA tools and mobility aids. For the given SS spiral, the work to develop the systems is required for Crew transportation from the surface of the Earth, to Earth Orbit, from Earth orbit to orbit around and/or the surface of the Moon or Mars, or other destinations (asteroids, Mars moons, etc), and for safe return to Earth.

4.n.12 In-Space Systems

In-Space Systems (InSS) includes spacecraft supporting both human and robotic exploration of the Moon, Mars, and other solar system bodies. This element can include logistics modules carrying fuel and supplies; spacecraft positioned to support communication, navigation, and/or reconnaissance requirements; and rendezvous/docking and robotic vehicles to support assembly in space. In-Space Systems will typically be free-flying spacecraft and include the subsystems to provide communications, command, and control, power, thermal control, and propulsion for orbit maintenance, maneuvering, and docking. In-Space Systems will also include all modifications/additions to the unique ground based communications assets(such as the Deep Space Network) to provide communications and navigation functions for human and robotic exploration. This element also includes all engineering, design, development, production, assembly, and test efforts to deliver the completed and qualified InSS, as well as the necessary unique support equipment to test, process, certify, transport, and operate the InSS.

4.n.12.1 In-Space Systems Management Team

SEE APPENDIX B

4.n.12.2 RFP/SEB Support

SEE APPENDIX B

4.n.12.3 In-Space Systems IPT Support

SEE APPENDIX B

4.n.12.3.1 Systems Engineering & Integration

SEE APPENDIX B

4.n.12.3.2 Constellation Systems Analysis

SEE APPENDIX B

4.n.12.3.3 Cost Engineering

SEE APPENDIX B

4.n.12.3.4 Safety & Mission Assurance

SEE APPENDIX B

4.n.12.3.5 Operations

SEE APPENDIX B

4.n.12.3.6 Human Centered

SEE APPENDIX B

4.n.12.3.7 Structural, Mechanical, Materials & Manufacturing

SEE APPENDIX B

4.n.12.3.8 Command, Control & Communications
SEE APPENDIX B

4.n.12.3.9 Ground Infrastructure
SEE APPENDIX B

4.n.12.3.10 Aerosciences & Flight Mechanics
SEE APPENDIX B

4.n.12.3.11 Propulsion & Fluids
SEE APPENDIX B

4.n.12.3.12 Power Systems
SEE APPENDIX B

4.n.12.3.13 Computer, Software, Automation
SEE APPENDIX B

4.n.12.3.14 Robotics
SEE APPENDIX B

4.n.12.4 In-Space Systems Prime Contractor
SEE APPENDIX B

4.n.12.4.1 System Management
See Appendix B Tier 3 Constellation Functional Work Template

4.n.12.4.2 Systems Engineering
See Appendix B Tier 3 Constellation Functional Work Template

4.n.12.4.3 Safety and Mission Assurance
See Appendix B Tier 3 Constellation Functional Work Template

4.n.12.4.4 Reserved

4.n.12.4.5 Integration and Test
See Appendix B Tier 3 Constellation Functional Work Template

4.n.12.4.6 Operations
See Appendix B Tier 3 Constellation Functional Work Template

4.n.12.4.7 In-Space Contract End Item Systems
See Appendix B Tier 3 Constellation Functional Work Template

4.n.13 Robotic Mission Systems

Robotic Precursor Systems (RPS) include a range of robotic missions directly supporting human exploration. The purpose of the RPS missions includes characterizing Exploration destinations, validating key technologies supporting exploration, and preparing for and supporting future human missions. Robotic Precursor Systems include Orbiters and Landers and the associated subsystems necessary to accomplish the specific mission.

4.n.13.1 System Management

See Appendix B Tier 3 Constellation Functional Work Template

4.n.13.2 Systems Engineering

See Appendix B Tier 3 Constellation Functional Work Template

4.n.13.3 Safety and Mission Assurance

See Appendix B Tier 3 Constellation Functional Work Template

4.n.13.4 Reserved

4.n.13.5 Integration and Test

See Appendix B Tier 3 Constellation Functional Work Template

4.n.13.6 Operations

See Appendix B Tier 3 Constellation Functional Work Template

4.n.13.7 Robotic Precursor Contract End Item Systems

See Appendix B Tier 3 Constellation Functional Work Template

4.n.13.8 Mars Reconnaissance Orbiter

This element encompasses all the work (data, products, and services) required to develop, deliver, and operate a lunar mapping reconnaissance orbiter. It includes the spacecraft, payload, launch vehicle, mission operation, ground system, and the management, systems engineering, and mission assurance elements necessary for successfully delivering the lunar topographic and resource data products.

4.n.13.9 Mars Robotic Lander

This element encompasses all the work (data, products and services) required to develop, deliver, and operate a robotic lander on the surface of the moon. It includes the spacecraft, payload, launch vehicle, mission operation, ground system and the management, systems engineering, and mission assurance elements necessary for successfully delivering the lunar surface resource verification products

4.n.14 Cargo Module

SEE APPENDIX B

4.n.14.1 Cargo Module Management Team
SEE APPENDIX B

4.n.14.2 RFP/SEB Support
SEE APPENDIX B

4.n.14.3 Cargo Module IPT Support
SEE APPENDIX B

4.n.14.4 Cargo Module Prime Contractors
SEE APPENDIX B

4.n.14.4.1 System Management
See Appendix B

4.n.14.4.2 Systems Engineering
See Appendix B

4.n.14.4.3 Safety and Mission Assurance
See Appendix B

4.n.14.4.4 Reserved
See Appendix B

4.n.14.4.5 Integration and Test
See Appendix B

4.n.14.4.6 Operations
See Appendix B

4.n.14.4.7 Cargo Module Contract End Item Systems
See Appendix B

4.n.15 Cargo Launch Vehicle
SEE APPENDIX B

4.n.15.1 Cargo Launch Vehicle Management Team
SEE APPENDIX B

4.n.15.2 RFP/SEB Support
SEE APPENDIX B

4.n.15.3 Cargo Launch Vehicle IPT Support
SEE APPENDIX B

4.n.15.4 Cargo Launch Vehicle Prime Contractors
SEE APPENDIX B

4.n.15.4.1 System Management
See Appendix B

4.n.15.4.2 Systems Engineering
See Appendix B

4.n.15.4.3 Safety and Mission Assurance
See Appendix B

4.n.15.4.4 Reserved
See Appendix B

4.n.15.4.5 Integration and Test
See Appendix B

4.n.15.4.6 Operations
See Appendix B

4.n.15.4.7 Cargo Launch Vehicle Contract End Item Systems
See Appendix B

4.n.16 Surface Systems
SEE APPENDIX B

4.n.16.1 Surface Systems Management Team
SEE APPENDIX B

4.n.16.2 RFP/SEB Support
SEE APPENDIX B

4.n.16.3 Surface Systems IPT Support
SEE APPENDIX B

4.n.16.4 Surface Systems Prime Contractors
SEE APPENDIX B

4.n.16.4.1 System Management
See Appendix B

4.n.16.4.2 Systems Engineering
See Appendix B

4.n.16.4.3 Safety and Mission Assurance

See Appendix B

4.n.16.4.4 Reserved

See Appendix B

4.n.16.4.5 Integration and Test

See Appendix B

4.n.16.4.6 Operations

See Appendix B

4.n.16.4.7 Surface Systems Contract End Item Systems

See Appendix B

4.n.17 Ascent/Descent Systems

As applied to Lunar Missions, Systems required to transport crew and cargo from the destination orbit to the destination surface.

4.n.17.1 Ascent/Descent Systems Management Team

SEE APPENDIX B

4.n.17.2 RFP/SEB Support

SEE APPENDIX B

4.n.17.3 Ascent/Descent Systems IPT Support

SEE APPENDIX B

4.n.17.4 Ascent/Descent Systems Prime Contractors

SEE APPENDIX B

4.n.17.4.1 System Management

See Appendix B

4.n.17.4.2 Systems Engineering

See Appendix B

4.n.17.4.3 Safety and Mission Assurance

See Appendix B

4.n.17.4.4 Reserved

See Appendix B

4.n.17.4.5 Integration and Test

See Appendix B

4.n.17.4.6 Operations

See Appendix B

4.n.17.4.7 Ascent/Descent CEI Systems Contract End Item Systems

See Appendix B

4.n.17.4.8 Contract End Item 1

SEE APPENDIX B

5.0 Exploration Systems Research and Technology

5.1 Advanced Space Technology Program

The ASTP is the portion of the H&RT portfolio that addresses relatively low TRL technologies, with the goal of exploring innovative concepts and advancing a range of high-leverage technologies. The goal is to validate these new concepts and technologies experimentally or analytically and to transition them for application in the Exploration Systems Enterprise and other NASA Enterprises. The nominal path for this transition will be through the Technology Maturation Program (discussed below), which will adopt, mature and demonstrate the most promising candidates for ultimate transition to flight system development projects.

5.1.1 Advanced Studies, Concepts and Tools Program

This program will explore revolutionary exploration system concepts and architectures; performs technology assessments to identify and prioritize mission enabling technologies; develops advanced engineering tools for systems analysis and reducing mission risk; and conducts exploratory research and development of emerging technologies with high potential payoff. Activities within this ASTP Element Program will provide products in support of both ASTP and TMP within H&RT, as well as for external customers/stakeholders—particularly within the OexS Requirements Division.

5.1.2 Advanced Materials and Structural Concepts Program

This program will develop high-performance materials for vehicle structures, propulsion systems, and spacesuits; structural concepts for modular assembly of space infrastructure and large apertures; lightweight deployable and inflatable structures for large space systems and crew habitats; and highly integrated structural systems and advanced thermal management technologies for reducing launch mass and volume.

5.1.3 Communications, Computing, Electronics & Imaging Program

This program will develop advanced space communications and networking technology; high-performance computers and computing architectures for space systems and data analysis; low-power electronics to enable robotic operations in extreme environments; and imaging sensors for machine vision systems and the characterization of planetary resources.

5.1.4 Software, Intelligent Systems & Modeling Program

This program will develop reliable software and revolutionary computing algorithms; intelligent systems to enable human-robotic collaboration; intelligent and autonomous systems for robotic exploration and to support human exploration; and advanced modeling and simulation methods for engineering design and data analysis.

5.1.5 Power, Propulsion & Chemical Systems Program

The Power, Propulsion, and Chemical Systems Research and Technology Program develops high-efficiency power generation, energy storage, and power management and distribution systems to provide abundant power for space and surface operations;

advanced chemical, and electrical space propulsion systems for exploration missions; chemical systems for the storage and handling of cryogens and other propellants; chemical systems for identifying, processing, and utilizing planetary resources; and chemical detectors and sensors.

5.2 Technology Maturation Program

The H&RT Technology Maturation Program (TMP), comprising mid- to high-TRL technology maturation, demonstration and flight experiments, will pursue new technologies in the areas of high energy space systems, advanced space systems and platforms, advanced space operations, and lunar & planetary surface operations. The program will advance key technologies required to enable the U.S. Exploration Vision, with a focus on the human and robotic exploration of the Moon, Mars and other destinations.

As indicated in Section 6.2, the TMP will rely on the ASTP Advanced Studies, Concepts and Tools Program for key products (e.g., study results, models, etc.) in support of ongoing program integration, planning and management.

5.2.1 High Energy Systems Technology Program

This program will examine a range of key technology options associated with future space exploration systems and architectures that are 'energy rich'—including high power space systems, highly efficient and reliable space propulsion systems, and the storage, management and transfer of energy/propellants in space. It may also address (as appropriate) high-energy maneuvering; including aero-entry, aero-braking, and other aero-assist related R&D. Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration. The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs. The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

5.2.2 Space Platforms and Systems Technology Program

The Advanced Space Systems and Platforms Technology Program will examine a range of key technology options associated with future space exploration systems and architectures that are resilient, reliable and reconfigurable through the use of miniaturization, modularization of key functions in novel systems approaches. Platforms technologies that support self-assembly and in-space assembly, as well as in-space maintenance and servicing will be included. These efforts will be closely coordinated with in-space assembly and related R&D within the Space Operations Technology Program (e.g., involving extra-vehicular activity (EVA) systems, robotics, etc.). Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration.

The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs. The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

5.2.3 Space Operations Technology Program

This program will examine a range of key technology options associated with future space exploration systems and architectures that involve a variety of combinations of advanced robotic and human capabilities, ranging from remotely tele-supervised robotic systems, through locally-teleoperated systems, to focused human presence (with robotic agent assistance). Technologies that enable in-space assembly, maintenance and servicing will be included. Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration. The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs.

These efforts will be closely coordinated with spacecraft subsystem, system, and related R&D within the Space Platforms and Systems Technology Program. The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

5.2.4 Lunar and Planetary Surface Operations Technology Program

The Lunar and Planetary Surface Operations Technology Program will examine a range of key technology options associated with future lunar and planetary surface exploration and operations for a range of increasingly-ambitious human and robotic mission options through the development of in situ resource utilization technologies, highly-capable surface mobility systems, and various supporting infrastructures. Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic lunar and planetary surface exploration in support of the U.S. Vision for Space Exploration.

The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs. The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

5.2.5 In-Space Technology Experiments Program

The In-Space Technology Experiments Program (In-STEP) will pursue both low- to mid-TRL flights of novel technologies, where appropriate, in addition to supporting the development and deployment (where required) of key infrastructures and carriers for such technology flight experiments (TFEs). The In-STEP effort will engage not only the other element programs within the H&RT Technology Maturation Program, but also possible TFEs emerging from the Advanced Space Technology Program and a range of other key technology options associated with future human and robotic space exploration and operations. Key objectives will derive from the goal of technology validation in support of safe/reliable, affordable and effective systems and missions in support of the U.S. Vision for Space Exploration. The program will involve TFE definition studies, accommodations planning and development (if needed), TFE development, and eventually flight on a range of carriers (including the International Space Station). The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

5.3 Innovative Technology Transfer Partnerships

The Innovative Technology Transfer Partnerships (ITTP) comprises (1) technology transfer activities, (2) NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs. The FY2004 budget terminated the Commercial Technology Program. Under the cognizance of technology transfer activities, the program will continue to document and license technologies and make them available to the private sector as legislatively mandated and prudently manage NASA's intellectual property.

5.3.1 Small Business Innovation Research (SBIR) Technical Themes.

The Small Business Innovation Research (SBIR) Program provides an opportunity for small business-based innovators to become involved with NASA's R&D investment portfolio. SBIR serves the interests of all of NASA strategic Enterprises. Major SBIR technical themes include the following:

- **Technologies to Enable Human and Robotic Exploration**. This theme will involve those technologies needed for direct human and robotic exploration of our Solar System (i.e., the Moon, Mars and the other planets, moons and small bodies), and for remote observation-based exploration (such as the astronomical search for origins).
- **Technologies to Advance Earth System Science and Understanding of the Sun-Earth Connection**. This technical theme will involve technologies needed for both Earth orbiting and deep space missions, and other activities related to Earth system science and the Sun-Earth connection.
- **Technologies to Improve U.S. Aviation Systems and Operations**. This theme will involve both aircraft systems research and technology and air traffic control systems research and technology.

These themes should be used to guide the formulation of the Small Business Innovation Research (SBIR) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific 'projects' within the element program. The themes are inclusive of any related educational activities. For example, a future project—yet to be defined—might address one, two or several of these technical themes.

5.3.2 Small Business Technology Transfer (STTR) Technical Themes

The Small Business Technology Transfer (STTR) Program provides an opportunity for advanced technologies and new concepts to be transitioned more effectively and more rapidly from the university community to small business-based innovators and then to NASA's R&D investment portfolio. STTR serves the interests of all of NASA strategic Enterprises. Major STTR technical themes include the following:

- **Technologies to Enable Human and Robotic Exploration**. This theme will involve those technologies needed for direct human and robotic exploration of our Solar System (i.e., the Moon, Mars and the other planets, moons and small bodies), and for remote observation-based exploration (such as the astronomical search for origins).
- **Technologies to Advance Earth System Science and Understanding of the Sun-Earth Connection**. This technical theme will involve technologies needed for both Earth orbiting and deep space missions, and other activities related to Earth system science and the Sun-Earth connection.
- **Technologies to Improve U.S. Aviation Systems and Operations**. This theme will involve both aircraft systems research and technology and air traffic control systems research and technology.

These themes should be used to guide the formulation of the Small Business Technology Transfer (STTR) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific 'projects' within the element program. The themes are inclusive of any related educational activities. For example, a future project—yet to be defined—might address one, two or several of these technical themes.

5.3.3 Technology Transfer Technical Themes

The Technology Transfer (TT) Program supports the timely transfer of technology into and out of the full suite of NASA's applied research, technology and development programs. Major TT technical themes include the following:

- **NASA Field Center Technology Transfer Offices**. This technical theme primarily addresses the establishment and maintenance of key working relationships between ITTP and Field Center level mission managers, their supporting personnel, and Field Center strategic planners, as well as brokering negotiations of agreements for transfer of technology into or out of the Agency.
- **Regional and National Technology Transfer Centers**. This theme primarily addresses the targeted identification, establishment, and maintenance of

relationships between ITTP and industry potentially leading to collaborations with NASA for transfer of technology into or out of the Agency, as well as supporting ITTP's brokering of resulting partnerships by providing industry sector-specific and other commercial perspective.

- **NASA Intellectual Property (IP) Efforts**. This theme support NASA efforts to protect and license Agency innovations and intellectual property.
- **Special Technology Transfer Projects**. This theme will involve any special projects as they may arise related to seeking innovative approaches to improve the infusion of new technologies into NASA's diverse programs. This theme also includes specific 'outreach' activities, such as publications and databases (e.g., Innovation magazine, NASA TechBriefs, etc.).

These themes should be used to guide the formulation of the Technology Transfer Agents (TTA) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific 'projects' within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes.

6 Human Systems Research and Technology

6.1 Life Support and Habitation Program

6.1.1 Advanced Life Support

This element of the WBS involves research and technology development to enable human space exploration for short and long duration travel in and beyond low Earth orbit, and on other planetary surfaces. The objectives are to provide a reliable human life-sustaining environment, to generate adequate supplies of life-sustaining resources, and to control the environment to enable productive human exploration activities. The activities involve Earth and space-based research and technology development and demonstration projects carried out by the NASA, private sector, and academic communities. Activities involve the delivery of specific technologies, sub-systems, integrated test results, and life support system design requirements and specifications. Activities will be primarily in the 1-6 TRL range, although exceptions will be made for projects extending to TRL 8-9 for flight validation.

6.1.1.1 Air Revitalization

Research objective is to conduct research for technology development to mid-TRL that will meet the functional requirements of the various spirals of the manned exploration vehicles. This includes potential ISS upgrades (Sabatier) as well providing for next generation systems for the CEV and Lunar Landers.

6.1.1.2 Water Reclamation

Research Objective is to develop mid-TRL technologies to transform crew and system wastewater into potable water for crew and system reuse under exploration mission scenarios.

6.1.1.3 Thermal Control

Research Objective is to develop next generation thermal management technologies by developing thermodynamically efficient heat acquisition, transport and rejection mechanisms.

6.1.1.4 Solid Waste Management

Research Objective is to develop capabilities for solid waste management ranging from sterilization and storage of waste, reclaiming life support commodities, depending on the life support system closure and/or mission duration.

6.1.1.5 Food Management System

Research Objective is to conduct research for technology development to provide for safe, acceptable and long-life foods for crew consumption with special emphasis on long shelf-life (up to 3 years) foods.

6.1.1.6 Biomass Production

Research Objective is to conduct basic and applied research to enhance capabilities of ALS biological components to enable further closure of the air, water, and food/waste loops.

6.1.2 Advanced Extra Vehicular Activities Systems

This element of the WBS contains research and technology development of a protective suit to enable human extravehicular activities (EVA) in space and in the hostile environment of extraterrestrial planetary surfaces. The EVA system includes EVA suits, airlocks, tools and mobility aids, and manned rovers. Because the EVA suit is essentially a miniature portable spacecraft, its advancement requires technology advances similar to those required in the development of a space vehicle. EVA R & D activities involve Earth and space-based research and technology development and demonstration projects carried out by the NASA, private sector, and academic communities. The activities involve the delivery of actual suit prototypes, sub-systems, integrated test results, and interfaces for EVA life support system design requirements and specifications. The EVA activities will be primarily in the 1-6 TRL range, although exceptions will be made for projects extending to TRL 8-9 for flight validation.

6.1.2.1 In-space Suit Technologies

Project/Research Objective is to develop suit assembly technologies including the pressure and protective garment, ancillary equipment, boots, gloves and helmet visor etc. to a TRL 6.

6.1.2.2 Surface Suit Technologies

Project/Research Objective is to develop the portable life support system (PLSS) that will enable EVA activities. The PLSS components include CO2 and O2 management, thermal control, power, medical, avionics and information systems along with self assisted rescue.

6.1.3 Advanced Environmental Monitoring and Control

This element of the WBS contains activities focusing on the development of robust and innovative technologies, components and sub-systems, control algorithms and data displays for the accurate and sustained monitoring and quality control of the crew environment. Miniaturization, low-level detection threshold with molecular resolution, multi-component sensitivities, integrated database and real-time analysis, low-power consumption, and spatial distribution are the primary technological challenges. The activities involve Earth and space-based research and technology development and demonstration projects carried out by the NASA, private sector, and academic communities. Activities will be primarily in the 1-6 TRL range, although exceptions will be made for projects extending to TRL 8-9 for flight validation.

6.1.3.1 Air, Water, Surface Monitoring

Research Objective is to develop micro/partial gravity compliant sensor technologies that are capable of monitoring air, water and surfaces for chemical and microbial contaminants at or below the spacecraft maximum allowable concentration level.

6.1.3.2 External Environment Monitoring

Research Objective is to develop capabilities to monitor the environment external to the astronaut habitat with special emphasis on EVA sensors and sensors for dust, reactive chemicals and particulates.

6.1.3.3 Life Support Integrated Controls

Research Objective is to provide integrated process control for life support systems to ensure proper operation, increased reliability and reduced crew time.

6.1.4 Contingency Response Technologies

This element of the WBS contains activities focusing on developing the capabilities to respond to inevitable contingencies by minimizing their occurrence and by providing the crew with effective responses. Areas of interest are fire safety and the ability to effect repairs to essential life support hardware. The activities involve Earth and space-based research and technology development and demonstration projects carried out by the NASA, private sector, and academic communities. Activities will be primarily in the 1-6 TRL range, although exceptions will be made for projects extending to TRL 8-9 for flight validation.

6.1.4.1 Fire Prevention, Detection, and Suppression

Project/Research Objectives are: address critical questions in areas of material flammability, fire detection, and fire suppression, provide data required to quantify factor-of-safety for spacecraft and habitat material selection, provide relevant low- and partial-gravity data for the design of fire protection system, and develop models of material flammability, transport of fire precursors, combustion products, and smoke.

6.1.4.2 In-situ Fabrication and Repair

Research Objective is to develop reliable Solid Freeform Fabrication, Radiation Shielding Fabrication and Soldering Technologies and Procedures to TRL 6.

6.1.5 In-situ Life Support Processes

Research Objective is to conduct research to mature technology necessary to extract life-support consumables from in situ regolith and atmosphere, to produce source materials for the In Situ Fabrication and Repair program, and to develop composites for use as radiation shelter materials.

6.1.6 Advanced Integrated Matrix

The integration of human support technology (HST), such as life support and environmental monitoring and control, necessitates a strong system engineering and integration (SE&I) capability to:

- Determine how a component performs within a subsystem
- Determine how subsystems/systems perform with the complex interaction of other systems:
- Provide an understanding of human interaction with the HST systems
- Ensure components will operate efficiently as a system
- Provide early mitigation of integration interfaces/issues
- Encourages cross-integration of HST elements

6.1.6.1 Integrated Requirements Assessment

Project/Research Objectives is to provide systems engineering for trade studies, analyses, integrated models, test results, and validated requirements for integration of HST elements

6.1.6.2 Integrated Models and Tests

Project/Research Objective is to provide a ground-based human-in-the-loop test integration capability to validate evolutionary integrated systems and to optimize system-level interfaces and interaction elements.

6.1.7 Applied Exploration Research

This element of the WBS contains activities focused on the low-gravity testing and validation of candidate technologies targeting human exploration requirements. ISS flight experiments and ground-based research will be carried out addressing near, mid, and long-term technology applications.

6.1.7.1 Advanced Materials Research

Research Objective is to deliver advanced materials in four target areas: Advanced Materials for Propulsion Systems, Vehicle Health Monitoring Materials, Environmental Protection Materials, Spacecraft Materials to meet spiral technology development milestones of NASA's exploration-dedicated programs.

6.1.7.2 Quantum Technology for Exploration

Project/Research Objectives: Perform directed research to develop quantum exploration technologies using SQUID-based and laser-cooled atom techniques and provide funding for current and future investigators to develop quantum exploration technologies.

6.1.7.3 Multiphase Flow Technology

Project/Research Objectives: To resolve issues with multiphase flow, stability and separation in low gravity as applied to human support technologies and power conversion.

6.1.7.4 Transition Research Projects

6.1.8 Program Management

6.1.8.1 Program Management

Management of program reviews and associated plans, system engineering management plan, program and project requirements documents, budget planning and execution, and strategic and tactical planning.

6.1.8.2 Research Integration and Management

Tactical implementation of research and technology development plans, NASA centers coordination and communication, research and development reviews.

6.1.8.3 Flight Projects Management and Support

Management of ISS and other flight development, operations, and integration activities.

6.1.9 Systems Engineering & Integration

6.1.9.1 Systems Engineering

6.1.9.2 Systems Integration

Integration of requirements, research planning, system-level testing planning and reports, configuration management, risk analysis and tracking, safety and mission assurance.

6.1.10 Cross Cutting Research Support

TBD

6.1.10.1 Ground Facilities and Capabilities

This element is responsible for the operations and maintenance of ground-based facilities and research capabilities such as Drop Towers, KC-135 research aircraft, Telescience Support Centers and other test facilities supporting research operations on the ground, on ISS and aboard other space assets.

6.1.10.2 In-space Facilities and Capabilities

This element of the WBS is responsible for the development of ISS facility-class hardware, such as the Fluids and Combustion Facility (composed of the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR)). Research-specific hardware is accounted for within its appropriate product WBS elements, not here.

6.1.10.3 Integration, Operations, and Sustaining Engineering

This element is responsible for the integration and operations, and sustaining engineering of flight equipment, as well as facility-class ground units (the ground integration unit, the engineering development unit, the trainers, and simulators). This element is also responsible for supporting GRC payloads integration with the International Space Station (ISS), including payload manifesting, integration, crew training and on-orbit operations.

6.2 Human Health and Performance

This element conducts research to identify and characterize health, environmental, and other operational human biomedical and performance risks associated with living in space and returning to earth, and to identify and deliver strategies, tools or technologies to mitigate (prevent or reduce) those risks.

6.2.1 Human Health Countermeasures

This element conducts research to identify and characterize the health and environmental human biomedical risks associated with living in space and returning to earth, and develops strategies, tools or technologies to mitigate those risks.

6.2.1.1 Artificial Gravity

Ground-based project designed to determine whether artificial gravity generated by centrifuge is a viable countermeasure candidate.

6.2.1.2 Exercise Systems

Research to develop reliable and instrumented exercise countermeasure hardware, optimized exercise prescriptions, ground testbeds, and next generation exercise hardware.

6.2.1.3 Pharmacology and Nutrition

Research to understand the pharmacokinetics and pharmacodynamics of medications in space, development of stable pharmaceuticals for treatment in space, optimal nutrition for long duration space flight, and nutritional effects on countermeasure effectiveness (exercise, AG, pharmacology, etc.).

6.2.1.4 Physiological Countermeasures

Physiological research in areas such as sensorimotor and neurological, cardiovascular, immunology, infection, hematology, and musculoskeletal alterations.

6.2.1.5 Research Enabling Facilities & Testbeds

6.2.2 Autonomous Medical Care

This element conducts the research to identify the needs and to develop the strategies, tools and or technologies to monitor health and provide medical care to the crew during space travel, and on the moon or Mars. Autonomous Medical Care is the focal point for research and development efforts in the areas of health care system technology, protocols, concepts of operation, and training, and medical information management tools and techniques.

6.2.2.1 Prevention Policies and Procedures

6.2.2.2 Monitoring Technologies

6.2.2.3 Diagnosis Capabilities

6.2.2.4 Treatment Tools and Techniques

6.2.3 Space Radiation

This element conducts research to understand and quantify the space radiation environment, to understand and quantify radiation risks, and to develop countermeasures to reduce or prevent impact of radiation risk.

6.2.3.1 Space Radiation Health

Includes development of biodosimeters and physical dosimeters to measure radiation exposure.

6.2.3.2 Space Radiation Shielding

6.2.4 Exploration Biology

This element will identify and define the scope of problems which will face future human space explorers, such as the possible effects of space flight on reproduction, on the plants that self-sustaining colonies will need in the future, or on changes in the virulence of common pathogens.

6.2.4.1 Exploration/Science Biology

6.2.4.2 Spaceflight Systems and Technologies

These investigations include research on model organisms chosen for their biological characteristics that are similar to humans or an aid to humans. These organisms include yeast, C. elegans, rodents and the plant Arabidopsis.

6.2.4.3 Exploration Biology Mission Elements

This element encompasses life support technology for model organisms and autonomous sample preparation and analysis. Such technologies include but are not limited to: sensors, detectors, arrays, imaging, photonics, and molecular/genomic/proteomic assays.

6.2.5 Program/ Science Management

This element encompasses all the work required for planning and control of resource management and management directives. Includes management of the Bioastronautics Critical Path Roadmap (BCPR) and related risk management activities. Provides cross-cutting management oversight, coordination, and integration of HH&P program and projects, advanced technology integration ensures critical technologies are available for human spaceflight, science management integration, assuring conformance of selected research with the BCPR.

6.2.5.1 Program Management

Program planning and control of resource management and management directives.

6.2.5.2 Program/Science Integration

Provides cross-cutting management oversight, coordination, and integration of HH&P program and projects. Advanced technology integration ensures critical technologies are available for human spaceflight. Sciences management integration, assuring conformance of selected research with the BCPR.

6.2.5.3 Grants Administration Management/Reporting

The ground-based grant project provides support to investigators and to the Bioastronautics Program. BCPR information relative to program goals is solicited from the investigators. The project provides the entry point for fundamental research leading to countermeasure development and implementation.

6.2.5.4 NSBRI

National Space Biomedical Research Institute, in partnership with NASA, is to lead a national effort for accomplishing the research necessary to support long-term human presence, development, and exploration of space and to enhance life on Earth by applying the resultant advances in human knowledge and technology acquired through living and working in space.

6.2.5.5 CEVP Management

Countermeasure Evaluation and Validation Program - focused on flight validation and countermeasure effectiveness. Will develop coordination strategy for countermeasure development partnered with NSBRI. Is a forcing function for a faster-to-flight process for maturing countermeasures.

6.2.5.6 Education and Outreach

The mission is to establish a comprehensive suite of programs and supportive materials that inspire people of all ages and walks of life to learn about the challenges of human space exploration and the potential benefits to life on Earth.

6.2.6 Cross Cutting Support

This element encompasses all the cross cutting tools, systems, models that enable more that one type of research and countermeasure development. This would include the animal and cell models, flight analogs, modeling studies, data bases and flight research.

6.2.6.1 Research Technologies

Develops tools, instruments and equipment that enable research to be performed. It is not a product such as a countermeasure, it is a product that would enable a countermeasure to be developed. For example, an instrument to perform better bone density measurements could be used to develop the best countermeasure against bone loss.

6.2.6.2 Flight Analogs

Ground based facilities that mimic the environments of space; used to perform research and gather knowledge used to develop countermeasure. Ex. Long Duration Bed Rest Capability or Isolation Chambers (Antarctic activities)

6.2.6.3 Cell/Animal Models and Systems

Research using cell and animal models will provide valuable insight into the following areas: pharmacology, physiological countermeasures, and, wound healing.

6.2.6.4 Modeling/Digital Astronaut

An integrated mathematical modeling & database systems that enables knowledge integration, provides analysis & understanding through simulation studies, supports experimental design and data analysis, and enables hypothesis testing and risk analysis.

6.2.6.5 Information Technology/Data Management

Information technology (IT) tools and services for Human Health & Performance, maintenance of Life Sciences Data Archive (LSDA) and website.

6.2.6.6 Flight ISSRC

Covers support systems to the Bioastronautics Flight research programs in human health and performance, covers development and maintenance of the HRF Racks 1 and 2, next generation UMS, and the MARES rack, provides ground facilities for development, testing, training, integration, and operations for ISS flight research.

6.3 Human Systems Integration

TBD

6.3.1 Space Human Factors Engineering

Research and development activities in space human factors engineering are focused on understanding human capabilities (physical and cognitive, and for individuals and teams) in the context of the space environment and of engineering system design factors, on understanding the crew requirements for the right type of information, and on building tasks and tools that are compatible with humans. The SHFE program products are validated models for human performance, methods for measuring human and human-system performance, requirements for mission design, tools, training, etc…, mission-specific human centered technologies. SHFE R & D activities involve Earth and space-based technology development and demonstration projects carried out by the NASA, private sector, and academic communities

6.3.1.1 Physical Performance Factors

Physical factors of two types critically affect human performance for space exploration. Environmental factors, including temperature, humidity, noise, lighting, free volume, privacy, and work station design, modify human performance capability. Human physical factors such as body size, strength, fatigue, and deconditioning limit the amount and types of work that can be performed. SHFE contributes to maintaining crew performance by predicting the effects of environmental factors and human physical

factors. To accomplish this, tools to assess human physical performance are required. Models predicting physical performance must be developed to support mission planning and equipment design. Requirements will be generated for operations, habitability, hardware and software design that will ensure human performance levels are maintained

6.3.1.2 Cognitive Performance Factors

Cognitive performance varies with changes in environmental factors, stress and fatigue, and time since training. Communications problems – time lags, noise, etc. – can contribute to decrements in cognitive performance. Information displays and decision making aids can either exacerbate or augment cognitive performance, depending on design and appropriateness. SHFE contributes to maintaining crew cognitive performance by developing tools to assess crew readiness to perform and to identify types of cognitive tasks most at risk. It develops models to predict cognitive performance to support mission planning and system interface design. Requirements are generated to ensure operation planning and interfaces contribute to successful cognitive performance.

6.3.1.3 Team Performance Factors

Many tasks – on earth and in space – are performed by multiple decision making agents. These teams can consist of crew members, ground support staff, or intelligent agents. Teamwork between robots and humans, between autonomous systems and humans, between ground and crew must be designed to use the strengths and compensate for the limitations of the team members. SHFE provides tools and guidelines for function allocation to enhance team performance. It develops measurements that can be used to identify successful or risky teamwork. It develops models to predict potential dangers and potential payoffs for various roles and combinations of agents. Requirements are generated to ensure operation planning and system interfaces contribute to successful task performance.

6.3.2 Behavioral Health and Performance

This element conducts research to identify and characterize the behavioral and performance risks associated with space travel and upon return to earth and to develop strategies, tools or technologies to mitigate those risks.

6.3.2.1 Psychosocial Adaptation

Develops prototypes for fitness for duty indicators for psychosocial adaptation, psychosocial adaptation, prototype for on-demand crew management training/intervention, protocols, procedures, and algorithms for astronaut candidate selection and crew selection.

6.3.2.2 Neurobehavioral Dysfunction/Disorder

Develops procedures, protocols, and algorithms to select out during astronaut candidate selections and crew select-out, neurobehavioral procedures, algorithms, models for dysfunctional mood or behavior, and clinical status evaluation protocol (CEVP).

6.3.2.3 Cognitive Task Performance

Develops unobtrusive monitoring, biomarker sentinels of cognitive dysfunction, protocols for training and intervention for cognitive dysfunction

6.3.2.4 Sleep and Circadian Rhythms

Understand and develop fitness for duty devices for fatigue. Develop protocols, algorithms and models, develop alertness and sleep deficit rehabilitation/protocols.

6.3.3 Systems Engineering/Requiremenets Management

TBD

6.3.4 Flight Systems and Support

6.3.4.1 Multi-User Systems and Support (MUSS)

This element of the WBS is responsible for International Space Station (ISS) payload manifesting, integration, and on-orbit operations. Manifesting activities are based on HQ and International Partner priorities. Integration functions include all products and services required to support preflight and on-orbit payload operations as well as all post flight payload activities. MUSS is responsible for implementing pre/post launch processing and associated safety reviews, as well as payload Certification of Flight Readiness (CoFR). MUSS provides real-time management of on-orbit operations using ground assets including the Payload Operations Integration Center (POIC), Payload Training Center (PTC). MUSS develops and sustains multi-user hardware systems for ISS including Conditioned Stowage equipment, Express and Express Rack derived systems, and ground test hardware and software. MUSS provides many multi-user and payload specific capabilities and hardware to US Payload Developers to support payload operations.

6.3.4.2 Free flyer missions (reserved)

This WBS covers those activities related to development and operations of free flyer systems and missions required to meet explorations requirements. This WBS element is currently reserved for future use.

6.3.4.3 Suborbital missions (reserved)

This WBS covers those activities related to development and operations of sub orbital systems and missions required to meet explorations requirements. This WBS element is currently reserved for future use.

7 Prometheus Nuclear Systems and Technology

7.1 Management and Administration

This WBS includes the overall management and administration efforts necessary to perform management and administrative planning, organizing, directing, coordinating, controlling, reporting, and approval processes for Prometheus.

7.1.1 Program Reviews, Oversight, Insights

This WBS includes all of Prometheus' formal reviews, major internal and external reviews, and over(in)sight activities.

7.1.2 Budgets

This WBS includes all of Prometheus' budget activities, including resource planning and control activities, maintenance of Prometheus schedules, and POP and other budget reviews.

7.1.3 Reserved

Reserved.

7.2 Regulatory and Policy

This WBS includes all regulatory and policy activities for Prometheus.

7.2.1 NEPA

This WBS includes all NEPA activities for Prometheus.

7.2.2 PDNSC 25/INSRP

This WBS includes all PDNSC 25 and INSRP activities required for Prometheus.

7.2.3 Launch Approval Engineering

This WBS includes all Launch Approval Engineering activities for Prometheus.

7.2.4 UNCOPUOS

This WBS includes all UNCOPUOS activities for Prometheus.

7.3 Policy

This WBS includes all Prometheus policy activities.

7.4 Reserved

7.5 Reserved

7.6 Advanced Systems Technology

This effort involves the development of advanced, large-scale, space nuclear power and propulsion technologies that would enable and/or substantially enhance human and robotic exploration missions, including future human exploration missions to Mars.

7.6.1 Management and Administration

This includes all Management & Administration activities for the AST element.

7.6.1.1 HQ Management

This includes all AST HQ Management activities for the AST element.

7.6.1.2 Reviews, Oversight, and Insights

This includes formal reviews, major internal and external reviews, and over(in)sight contracted activities for the AST element.

7.6.1.3 Launch Approval Engrg(LAE)/NEPA

This includes technical and management efforts necessary for developing and implementing the LAE/NEPA functions for the AST element.

7.6.1.4 Systems Safety Management

This includes technical and management efforts necessary for developing and implementing the system safety functions for the AST element.

7.6.1.5 Risk Management

This includes technical and management efforts necessary for developing and implementing the risk management functions for the AST element.

7.6.1.6 Communication, Engagement, and Outreach

Includes all AST Communication, Engagement, and Outreach activities for the AST element.

7.6.1.6.1 Communication Planning & Implementation

Incorporates standard NASA public affairs processes and products and ensures that they are informed by risk communications concepts related to imparting controversial information in unpredictable situations. Blends traditional public affairs operations with various media with risk communications processes and products and includes a range of activities such as review of all external technical and communications materials for clarity and consistency, as well as risk communication training for program spokespersons.

7.6.1.6.2 Engagement Planning & Implementation

Extends the traditional NASA public education and outreach concepts, closely guided by risk communication methodology, to actively initiate a dialog with the public about the risks and benefits of the use of space nuclear power. Engagement implies an exchange of information, opinion and perception. Engagement includes such activities as funding studies to understand the nature and extent of public interests and concerns, to developing a means to substantively enter into a long-term dialogue with potential stakeholders.

7.6.1.6.3 Outreach Planning & Implementation

Outreach grows out of traditional NASA educational programs that seek to increase public knowledge of space, science, and the space program in general and, whenever possible, inspire the next generation of explorers. It includes formal and informal education, curriculum development, informative materials, multimedia and displays, and meetings in which to impart this information. Outreach focuses on providing clear, consistent, and inspirational information, throughout the life of the program, while at the same time providing opportunities for increasing technological and scientific literacy.

7.6.1.7 Corporate G&A

Includes all AST Corporate G&A items for the AST element.

7.6.1.8 PEO Reserves

Includes all AST PEO Reserves activities for the AST element.

7.6.1.9 HQ Institutional Requirements

Includes all AST HQ Institutional Requirements items for the AST element.

7.6.2 Mission Design and Analysis

This includes all mission design and Analysis activities for the AST element.

7.6.3 Systems Engineering and Integration

This includes all System Engineering and Integration activities for the AST element.

7.6.3.1 Mission and Systems Analysis

This element includes the technical and management efforts necessary for conducting mission and systems analysis activities that support Prometheus. Identifies potential human and robotic exploration missions enabled or substantially enhanced by nuclear power and/or propulsion. Conducts mission and system analysis to assess mission break-points and optimize mission performance for advanced nuclear systems. Identify potential AST concepts/systems for these exploration missions enabled or substantially enhanced by these nuclear systems. Supports Requirements Division activities.

7.6.3.2 Technology Integration and Requirements Definition

This element includes the integration of technology functions of the various AST subsystems into a complete AST system that can meet exploration mission requirements. Identifies key nuclear technology requirements and needs, including nuclear technologies/systems that substantially enhance and/or enable future exploration missions. Support Requirements Division activities.

7.6.4 Reserved

7.6.5 Reserved.

7.6.6 Reserved

7.6.7 Reserved.

7.6.8 Adv. Nuclear Electric Propulsion (ANEP) Systems

This includes ANEP Systems R&D efforts within the AST element that support the Prometheus technology investment strategy.

7.6.8.1 ANEP Management and Direction

This includes management and direction efforts necessary to support the ANEP Systems subelement, including over(in)sight of contracted efforts.

7.6.8.1.1 ANEP Strategy to Task to Technology

This includes implementation of STT efforts for ANEP

7.6.8.1.2 ANEP Technology Roadmaps/Rqmts

This includes development of ANEP technology roadmaps, flowdown/incorporation of requirements, and identification of critical issues/decisions necessary to support ANEP Systems subelement.

7.6.8.2 High Power (20 to 50 kWe) NRAs

This includes technical and management efforts necessary to implement the High Power Nuclear Electric Propulsion (EP) NRA technology research contracts.

7.6.8.2.1 Stanford VHITAL (Hall EP) NRA

This includes technical and management efforts necessary to implement the subject (2-stage Bismuth-Fed Hall Thruster w/Anode Layer) NRA contract.

7.6.8.2.2 Busek Hall EP NRA

This includes technical and management efforts necessary to implement the subject EP NRA contract.

7.6.8.3 Very High Power (100 to > 250 kWe) NRAs

This includes technical and management efforts necessary to implement the Advanced Electric Propulsion (AEP) NRA technology research contracts.

7.6.8.3.1 Princeton MPD NRA

Includes technical and management efforts necessary to implement the Princeton Advanced Lithium-Fed Applied-field Lorentz Force Accelerator NRA contract.

7.6.8.3.2 NuPIT NRA

Includes technical and management efforts necessary to implement the Northrop Grumman Nuclear-Electric Pulsed Inductive Thruster System NRA contract.

7.6.8.4 Critical Issues in Electric Propulsion NRAs

This includes technical and management efforts necessary to implement the Critical Issues in Electric Propulsion (CIEP) NRA technology research contracts.

7.6.8.4.1 (TBD) NRAs

TBD. (Include after announcement of NRA proposals selections.)

7.6.8.5 Directed ANEP Technology R&D

This includes technical and management efforts necessary to implement directed ANEP technology research and development efforts.

7.6.8.5.1 Ion EP

This includes technical and management efforts necessary to implement directed Ion EP technology research and development efforts.

7.6.8.5.2 Hall EP

This includes technical and management efforts necessary to implement directed Hall EP technology research and development efforts.

7.6.8.5.3 Advanced EP

This includes technical and management efforts necessary to implement directed Advanced EP technology research and development efforts.

7.6.8.5.4 Reserved

Reserved. (TBD later.)

7.6.8.6 Directed ANEP Analysis & Modeling

This includes technical and management efforts necessary to implement directed ANEP analyses, modeling, and requirements definition efforts.

7.6.8.6.1 ANEP Life Modeling

This includes technical and management efforts necessary to implement directed ANEP life modeling efforts.

7.6.8.6.2 Reserved

Reserved. (TBD later.)

7.6.8.7 Directed ANEP Tests & Facilities

This includes technical and management efforts necessary to implement directed ANEP system tests and test facility development.

7.6.8.7.1 Long Life Cathode Testing

This includes technical and management efforts necessary to implement directed Long Life Cathode test facility development and related test activities.

7.6.8.7.2 Reserved

Reserved. (TBD later.)

7.6.9 Adv. Fission-based Power (AFP) Systems/Concepts

This includes AFP Systems/Concepts R&D efforts within the AST element that support the Prometheus technology investment strategy.

7.6.9.1 AFP Management and Direction

This includes management and direction efforts necessary to support the AFP Systems/Concepts subelement, including over(in)sight of contracted efforts.

7.6.9.1.1 AFP Technology Roadmaps/Rqmts

This includes development of AFP technology roadmaps, flowdown/incorporation of requirements, and identification of critical issues/decisions necessary to support AFP Systems/Concepts subelement.

7.6.9.1.2 AFP Surface Power Systems Def'n

This includes providing definition and preliminary designs of AFP surface power concepts and systems for future exploration missions.

7.6.9.1.3 AFP STT Implementation

This includes implementation of STT efforts for AFP elements.

7.6.9.2 High Power NRAs

This includes technical and management efforts necessary to implement the High Power Conversion NRA technology research contracts.

7.6.9.2.1 Brayton Power Conversion NRA

This includes technical and management efforts necessary to implement the subject NRA contract.

7.6.9.2.2 STMC NRA

This includes technical and management efforts necessary to implement the subject NRA contract.

7.6.9.2.3 Rankine Conversion NRA

This includes technical and management efforts necessary to implement the subject NRA contract.

7.6.9.3 Very High Power (> 150 kWe) NRAs

This includes technical and management efforts necessary to implement the Advanced Very High Power Systems NRA technology research contracts.

7.6.9.3.1 TBD NRAs

Reserved. (TBD later.)

7.6.9.4 Critical Issues in Power Systems NRAs

This includes technical and management efforts necessary to implement the Critical Issues in Power Systems (CIPS) NRA technology research contracts.

7.6.9.4.1 (TBD) NRAs

Reserved. (TBD later)

7.6.9.5 Directed AFP Technology R&D

This includes technical and management efforts necessary to implement directed AFP system technology research and development efforts.

7.6.9.6 Directed AFP Analysis, Modeling & Reqmts

This includes technical and management efforts necessary to implement directed AFP analyses, modeling, and requirements definition efforts.

7.6.9.7 Directed AFP Tests & Facilities

This includes technical and management efforts necessary to implement directed AFP system tests and test facility development.

7.6.10 Adv. Nuclear Propulsion (ANP) Concepts/Systems

This includes ANP Systems R&D efforts within the AST element that support the Prometheus technology investment strategy.

7.6.10.1 ANP Management and Direction

This includes management and direction efforts necessary to support the ANP Systems subelement, including over(in)sight of contracted efforts.

7.6.10.1.1 ANP Technology Roadmaps/Rqmts

This includes development of ANP Technology Roadmaps and Requirements necessary to support ANP Systems subelement.

7.6.10.1.2 ANP Concepts/Systems Def'n

This includes providing definition and preliminary designs of ANP concepts and systems for future exploration missions.

7.6.10.1.3 ANP Concepts/Systems STT Implementation

This includes implementation of STT efforts for ANP Concepts/Systems elements.

7.6.10.2 ANP NRAs/BAAs

Reserved. (Placeholder for technical and management efforts necessary to implement future ANP NRA/BAA technology research contracts.)

7.6.10.3 Reserved

7.6.10.4 Reserved.

7.6.10.5 Directed ANP Technology R&D

Reserved. (Placeholder for technical and management efforts necessary to implement future directed ANP technology research and development efforts.)

7.6.10.6 Directed ANP Analysis, Modeling & Reqmts

Reserved. (Placeholder for tech. & mgmt. efforts necessary to implement future directed ANP analyses, modeling, and requirements definition efforts.)

7.6.10.7 Directed ANP Tests & Facilities

Reserved. (Placeholder for technical and management efforts necessary to implement future directed ANP system tests and test facility development.)

7.6.11 Adv. Nuclear Vehicle/Spacecraft Systems (ANVSS)

This includes ANVSS Systems R&D efforts within the AST element that support the Prometheus technology investment strategy.

7.6.11.1 ANVSS Management and Direction

This includes management and direction efforts necessary to support the ANVSS Systems subelement, including over(in)sight of contracted efforts.

7.6.11.1.1 ANVSS Technology Roadmaps/Rqmts

This includes development of ANVSS Technology Roadmaps and Requirements necessary to support ANVSS subelement.

7.6.11.1.2 ANVSS Concepts/Systems Def'n

This includes providing definition and preliminary designs of ANVSS concepts and systems for future exploration missions.

7.6.11.1.3 ANVSS STT Implementation

This includes implementation of STT efforts for ANVSS elements.

7.6.11.2 ANVSS NRAs/BAAs

Reserved. (Placeholder for technical and management efforts necessary to implement future ANVSS NRA/BAA technology research contracts.)

7.6.11.3 Reserved

7.6.11.4 Reserved.

7.6.11.5 Directed ANVSS Technology R&D

Reserved. (Placeholder for technical and management efforts necessary to implement future directed ANVSS technology research and development efforts.)

7.6.11.6 Directed ANVSS Analysis, Modeling & Reqmts

Reserved. (Placeholder for tech. & mgmt. efforts necessary to implement future directed ANVSS analyses, modeling, and requirements definition efforts.)

7.6.11.7 Directed ANVSS Tests & Facilities

Reserved. (Placeholder for technical and management efforts necessary to implement future directed ANVSS tests and test facility development.)

7.6.12 Adv. Prometheus Reactor Systems (APRxS) - (DOE)

This includes APRxS Systems R&D efforts within the AST element that support the Prometheus technology investment strategy.

7.6.12.1 APRxS Management and Direction

This includes management and direction efforts necessary to support the APRxS subelement, including over(in)sight of contracted efforts.

7.6.12.1.1 APRxS Technology Roadmaps/Rqmts

This includes development of APRxS Technology Roadmaps and Requirements necessary to support APRxS subelement.

7.6.12.1.2 APRxS Concepts/Systems Def'n

This includes providing definition and preliminary designs of APRx concepts and systems for future exploration missions.

7.6.12.1.3 APRxS STT Implementation

This includes implementation of STT efforts for APRxS elements.

7.6.12.2 APRxS NRAs/BAAs

Reserved. (Placeholder for technical and management efforts necessary to implement future APRxS NRA/BAA technology research contracts.)

7.6.12.3 Reserved

7.6.12.4 Reserved.

7.6.12.5 Directed APRxS Technology R&D

This includes technical and management efforts necessary to implement directed APRxS technology research and development efforts.

7.6.12.6 Directed APRxS Analysis, Modeling & Reqmts

This includes technical and management efforts necessary to implement directed APRxS analyses, modeling, and requirements definition efforts.

7.6.12.7 Directed APRxS Tests & Facilities

This includes technical and management efforts necessary to implement directed APRxS tests and test facility development.

7.7 Reserved

7.8 Prometheus 1 Project Management & Systems Engineering

This WBS includes the overall integrated project management and systems engineering efforts to perform business and administrative planning, organizing, directing, coordinating, controlling, reporting, and approval processes, plus the technical and management efforts of directing and controlling integrated engineering and science disciplines to accomplish the Prometheus 1 Project objectives.

7.8.1 Project Management

The overall planning, organizing, directing, coordinating, reporting, and approval actions designed to accomplish the overall project objectives that are not associated with specific hardware elements and are not included in systems engineering. It includes defining the project requirements structure, information infrastructure, review structure, and facility

requirements. It also includes establishing and maintaining agreements with other NASA Centers and DOE.

7.8.1.1 Project Manager Staff

Lead and provide the primary customer interface for the Project. Includes Project Manager, Deputies, if any, secretaries, APTs and other Project Office support personnel.

7.8.1.1.1 JPL Project Staff

Lead and provide the primary customer interface for the Project at JPL. Includes Project Manager, Deputies, if any, secretaries, APTs and other Project Office support personnel.

7.8.1.1.2 DOE Project Staff

Leads and provides the primary customer interface for the Project at DOE. Deputy for Nuclear provides direction and oversight to ensure responsible execution of DOE statutory authority for nuclear design, safety, and operations.

7.8.2 Mission Assurance

Mission Assurance Manager overseeing Mission Assurance for the entire Project. Responsible for the following disciplines: Quality Assurance for Hardware & Software, EEE Parts, Reliability, Environments, Materials & Processes, Contamination Control, Space Systems Assurance, Systems Safety, and Launch Approval. Provides risk assessment to the Project, interfaces with contractors and other governmental agencies, and provides an independent assessment of the "health" of the Project.

7.8.2.1 Mission Assurance Management

Need Description

7.8.2.2 Risk Management

Risk Management works to satisfy the requirements of JPL D-16993, Office of Space Science Risk Communication for Planetary and Deep Space Missions. Provides a coordinated approach to communication with the media, public, educators, legislators, and governmental bodies with regard to NASA missions that might have environmental or safety issues of greater than ordinary concern to members of these groups. Represents the Project interests at all risk communication planning meetings and reviews and provide liaison functions with internal JPL offices, NASA HQ, and other industrial partners/subcontractors as required. Documentation products might include responses to questions (RTQs), fact sheets, and a project-specific risk communication plan.

7.8.2.2.1 Risk Management & Engineering

The PROMETHEUS 1 Risk Manager will: provide the leadership in the Risk Management process for all NASA Centers, JPL, DOE, and Project partners and obtains results required to effectively assist the Project Manager in making timely programmatic decisions that have a direct impact on mission success.

7.8.2.2.2 Risk Management Contracts

This WBS supports WBS 1.5.7.1, Risk Management Engineering. All contracts related to procurement of software products and associated customization/upgrades are included under this WBS.

7.8.2.3 Reviews Project

Reviews: Provide human resources and facilities for the Project's formal, major internal reviews, including: the concept review (CR), the preliminary mission and system review (PMSR), the preliminary design review (PDR), the critical design review (CDR), and the pre-ship review (PSR). Includes preparation of subsequent board RFAs and board reports. Costs include travel expense for board members, labor cost for JPL direct and external board members, reproduction costs, and conferencing facilities expenses for independent cost estimates. Excludes costs for independent reviews, such as red teams, and "peer review" costs, which should be kept by the respective system or SS accounts.

7.8.3 Business Operations

Business Operations includes all Project resource planning and control activities, maintenance of the Project schedule, financial control, production of cost estimates and operation of the Project performance measurement and reporting systems.

7.8.4 Science and Mission Design

The technical and management efforts of directing and controlling the science investigation aspects of the Project. This includes the efforts associated with defining the science requirements; ensuring the integration of the science requirements with the instruments, payloads, and flight system; providing the algorithms and SW for science data processing and analyses; science data analysis and archiving. Excludes HW and SW for on-board science investigative instruments / payloads. Includes all activities related to the development and planning of the mission trajectories and navigation tools.

7.8.4.1 Science Management

Manage relationships between other elements of the Project and the science investigators. Lead the science activities of the Project. Supervise the science liaison personnel. Includes, for example: participating in Project reviews and other types of Project activities, maximizing scientific return within Project constraints, chairing the Project Science Group, serving as scientific spokesperson for the Project, managing the data archiving process, planning for science operations and data analysis, science implementation schedules, science document configuration control, and monitoring of science support contracts.

7.8.4.2 Instrument Acquisition

Coordinate the acquisition of all science instruments for the Project. This effort terminates upon selection of instrument proposals by NASA HQ. The actual costs for developing the instruments are covered in WBS elements 3.4.2.2, 3.4.3.2, and 3.4.4.2. The Contract Technical Managers for instrument contracts are covered under WBS elements 3.4.2.1, 3.4.3.1, and 3.4.4.1.

7.8.4.3 Science Data Management

Science investigators selected to provide interdisciplinary science expertise to the Project, including participation in the Project Science Group, and coordinated and synergistic analysis of data from multiple instruments in the payload. Does not involve any instrument development.

7.8.4.4 Mission Design

The complex of equipment, data, services, human resources, and facilities required to design the mission scenarios. Includes, for example: launch and trajectory analysis, orbit and maneuver design, ephemeris, DSN requirements and corrections for small forces.

7.8.4.4.1 Mission Design

Plan and develop the end-to-end mission scenarios for the Project. Includes, for example: developing planning and operational guidelines and constraints for the mission, supporting DSN requirements and interface definition, developing Earth-relative departure targets for the launch vehicle upper stage, evaluating utilization of the launch period, developing the end-to-end baseline trajectory design (injection through planetary quarantine orbit), analyzing the trajectory and orbit design of the various mission phases for compliance with planetary protection requirements, and providing system administration support for Unix computers owned and operated by the Mission Design Team. The main products are the Mission Requirements Document, Target Specification, Mission Plan, and Trajectory Characteristics document. The official Mission Design Procedure is given in: http://dmie.jpl.nasa.gov/cgi/doc-gw.pl?DocID=31932

7.8.4.4.2 Mission Engineering Technology

Design and implement low-thrust trajectory tools for mission and trajectory design and navigation on the basis of the timely transformation of an incomplete existing assortment of ad-hoc tools (intended for Pre-phase-A preliminary analysis tools and/or research and prototyping of new algorithms), resulting in a complete and integrated software set suited to full life-cycle support of a first-of-kind, real-world mission. It will be necessary to have a fully operational, delivered, maintainable set of trajectory and mission design software by Phase C (CY2007) and navigation software by Phase D (CY2009).

7.8.4.5 Science Environmental Characterization

Provide science advice on characterization of the atmosphere and surface of the target destination. Assist with the development of the ERD. Participate in meetings with scientists and Project engineers to provide best estimates and uncertainties for key environmental characteristics.

7.8.4.6 Communications & Information Systems

Information System Engineering and Communications: Provide Project team communications, information technology architecture, and data organization, retrieval, and archiving to support the "virtually co-located" Project, which includes partners/major subcontractors and international partners. Coordinate and facilitate audio and video conferencing among the remote locations. Identify, integrate, and adapt Project-specific

and institutional tools and repositories for Project team use. Assure compliance with: International Standards Organization (ISO) 9001; NASA Procedures and Guidelines (NPG) 7120.5; International Traffic in Arms Regulations (ITAR); Export Administration Regulations (EAR); JPL institutional management requirements. Extend information environment to the launch site.

7.8.5 Project Engineering

This effort is for the technical and management efforts of directing and controlling an integrated engineering effort for the systems of the Project. It includes, for example: the effort to define and specify the Level 2 Requirements on the Mission Operations System, the Space System, and the Launch System; the integrated planning and control of the technical program efforts of system engineering, the development of the Project- and system-level validation and verification requirements; the effort to transform operational Project objectives into a description of system requirements and a preferred system configuration; the technical oversight and control effort for planning, monitoring measuring, evaluating, directing, and replanning the management of the technical program, including risk management and configuration management. Documentation Products include: Master Control Document List, Mission/System Requirements Document (MSRD); Interface Control Documents (ICDs); Risk Management Plan; and Verification and Validation (V&V) Plan.

7.8.5.1 Project System Management

Project System Engineering Management: Lead the Project's overall system architecture, definition, and engineering functions by efforts of the Project System Engineer/Chief Engineer. Includes requirements structure, flow-down, definition, and management; defining intersystem interfaces, Project external interfaces, and test plans; conducting trade studies; and managing Project technical resources and risk. Runs the Project system engineering team and manages the Project action-item list. Also includes Project engineering document development tasks, such as the Project review plans, the system engineering management plan, system engineering reports, Project requirements documents, system description documents, ICDs, V&V requirements, and Project test plans and test/verification matrix.

7.8.5.2 Project System Engineering

Project System Engineering Staff: Define and implement the Project's overall system architecture and perform engineering functions as members of the Project system engineering team. Includes requirements structure, flow-down, definition, and management; defining intersystem interfaces, Project external interfaces, and test plans; conducting trade studies; managing Project technical resources and risk; manage the Project action-item list. Also includes Project engineering-document development tasks, such as system engineering reports, Project requirements documents, system description documents, ICDs, V&V requirements, and Project test plans and test/verification matrix.

7.8.5.3 System Fault Protection Engineering

All activity related to system-level fault protection engineering.

7.8.5.4 Project Software Engineering

Project Software Engineering: Develop the system SW architecture and provide the Project SW systems engineer. Includes developing SW policies and practices; working developing SW requirements, designing and implementing the SW resolving test issues, and making flight/ground tradeoffs; providing for the Project interface (along with SW QA liaison) to NASA's WVa IV&V center. Documentation products include the Software Management Plan.

7.8.5.5 E-T-E Information Systems

End-to-End Information System: Provide for end-to-end information system (EEIS) engineering for the Project science and/or technology data stream. Includes analysis and validation of data streams from instrument/payload collection points through the payload-spacecraft interface; downlinking; collection in the GDS; data processing; and delivery to recipients.

7.8.5.6 Launch System Engineering

Launch System Engineering: Provide the liaison interface between Launch System and all other Project systems and the primary interface between the Project and the launch services provider. Launch services costs are excluded.

7.8.5.7 Left Intentionally Blank

7.8.5.7.1 Left Intentionally Blank

7.8.5.7.2 Left Intentionally Blank

7.8.5.8 Project Verification & Validation

Project Verification and Validation: Perform requirements V&V on the Project systems. Key products include the Project V&V Plan.

7.8.5.9 Planetary Protection

Planetary Protection: Ensure that the project meets all NASA PP requirements. Includes performing analyses; drafting and submitting documentation to the appropriate national agencies; and interfacing with industrial, foreign, US Agency, NASA center, and university partners/subcontractors and reviewing their analyses for compliance with requirements.

7.8.5.10 Configuration Management

Configuration Management: Provide the interface with and coordinate configuration management (CM) activities between the Project (that is, JPL) and industrial, foreign, United States (US) agency, NASA center, and university partners to provide the required change visibility with all interacting and interdependent elements of the Project and to ensure interface control between various Project elements. Includes establishing and managing the JPL project-level change control board; coordinating change activity between the Project and industrial team partners; and providing operational guidance on

CM issues. Also includes the costs of the EDMG and/or product data management system (PDMS).

7.8.5.11 Left Intentionally Blank

7.8.5.12 Left Intentionally Blank

7.8.6 Safety

This WBS provides Mission Safety engineering to the Project. It includes, Environmental and Health, Launch Approval (LA) Engineering, National Environmental Protection Act (NEPA) Compliance, Nuclear Safety, Nuclear Safeguards, and Systems Safety.

7.8.6.1 LA/NEPA

Coordinate the launch approval efforts, including Launch Approval planning and oversight, Launch Vehicle Databook input planning and review, and launch integration and planning. Also includes procurement of services such as safety analysis, testing and emergency response pre-deployment.

7.8.6.2 Safety Management

This effort provides all management for the overall safety efforts for the Project.

7.8.6.3 Nuclear System Safety & Assurance (DOE)

This effort provides Project oversight for nuclear safety, mission assurance, safeguards, and security aspects of all Project elements having an impact on operations involving special nuclear materials.

7.8.6.4 Systems Safety

Provide all management for the overall safety efforts of the Project. Deliver to the Project a completed System Safety Program Plan, Hazards Analyses, Missile System Pre-launch Safety Package, Ground Operations Safety and Contingency Plan; Perform System Safety Surveys; and provide system safety oversight throughout the design, build, test, launch processing phases. Receive inputs from designated Project elements to complete the MSPSP and to design and test engineering support for reviews and deliverables to KSC and Range Safety.

7.8.7 Public Engagement

PROMETHEUS 1 Public Engagement provides education, public outreach and external communications aspects of the Project. It includes labor and materials associated with exhibits and seminars in schools and museums; Project web page design and maintenance; and subcontracts to other Public Engagement partners.

7.8.8 Ground System

"The PROMETHEUS 1 Ground System (GS) is the ground-based system required to conduct PROMETHEUS 1 mission operations and consists of all of the following implementation components:

a) Personnel - Trained and certified people required to conduct mission operations
b) Procedure – Set of documented steps executed by flight team members to ensure that mission operations are conducted in a reliable, consistent, and controlled manner
c) Facilities - Offices, conference rooms, laboratories, and other work-space housing the personnel, procedure, hardware and software components of the MOS; includes all associated documentation
d) Hardware - Ground-based communications and computing hardware and associated documentation required to conduct mission operations
e) Software - Ground-based software and associated documentation required to conduct mission operations
The purpose of mission operations is to plan, control, monitor, and analyze the mission activities of the PROMETHEUS 1 Space System (SS) and manage, process, archive, and deliver to the users the mission data collected from the PROMETHEUS 1 SS."

7.8.9 Ground System Management & Systems Engineering

The integrated GS management and systems engineering efforts to perform planning, controlling, monitoring, and approval of the combined efforts of engineering and science disciplines needed to deliver the GS and operate the SS.

7.8.9.1 Ground System Management

Leadership and management of resources (e.g., personnel, budget, schedule) for delivery of the GS and operations of the SS. This effort includes definition of management practices for GS configuration management, software development, mission assurance, and make/buy decisions; negotiation of management agreements with GS implementing organizations (e.g., IND, science investigations); liaison with the SS Development Manager to ensure that the interfaces between the GS and SS are adequately defined and with PROMETHEUS 1 customers to ensure that PROMETHEUS 1-to-customer interfaces are adequately defined; participate in Project-level reviews; and lead GS-level reviews.

7.8.9.2 Ground System Assurance

Ensuring that GS development staff follow proper design and implementation processes in GS development and that operations staff follow proper processes and procedures in executing operations. This effort includes, for example, oversight of pre-launch preparation activities and support to ensure the continuing capability of the Problem Reporting System during GS development and operations.

7.8.9.3 Ground System Engineering

"The system-level technical effort to design a Ground System that satisfies customer needs and verify that it does so. This effort includes: identification and quantification of system requirements based on customer needs, creation of alternative system design concepts, performance of design trades, and selection and implementation of the best design."

7.8.10 Mission Operations Module

The Mission Operations Module (MOM) includes the Deep Space Network (DSN) tracking, command, telemetry, and radio metric data delivery, mission data management, mission monitor & control, navigation, engineering analysis, mission planning, and sequencing functions. The JPL Interplanetary Network Directorate (IND) supplies the DSN tracking and the command, telemetry, and radio metric data delivery, mission data management, and ancillary data product formatting functions as Deep Space Mission System (DSMS) Services to the PROMETHEUS 1 Project.

7.8.10.1 Mission Operations Module Management & Systems Engineering

The integrated MOM management and systems engineering efforts to perform planning, controlling, monitoring, and approval of the efforts needed to deliver the MOM.

7.8.10.2 Mission Operations Module Facilities & Systems Administration

Designs and provides the facilities component of the Mission Operations Module and provides administration for the computing and networking capabilities in the Mission Operations Module.

7.8.10.3 Mission Monitoring & Control Segment

This effort provides the following operational functions: monitoring SS health; monitoring the status of DSN antennas and telemetry and command processing capabilities; controlling SS command sessions; and implementing contingency actions in response to detected anomalies.

7.8.10.4 Navigation Segment

This effort provides the following operational functions: low-thrust trajectory design and analysis, generation of predicted and reconstructed ephemeris of the SS, and maneuver design and analysis.

7.8.10.5 Sequencing Segment

Provides the following operational functions: DSN scheduling, translation of mission plan and activity requests into sequences of SS commands, integration of these sequences with other engineering and instrument subsequences, identification and resolution of conflicts in integrated sequences, verification of integrated sequence's safety (i.e., compliance with flight rules and constraints and resolution of any non-compliance) and effectiveness (i.e., ability to carry out intended activities), and generation of sequence of events.

7.8.10.6 Mission Planning Segment

This effort provides the following operational functions: establishment of major science and engineering objectives, establishment of guidelines and constraints for the use of resources during operations, long-range planning for DSN antenna resources, high-level integration of science and engineering plans for Flight System activities, and contingency planning. The activity provides personnel to plan mission activities. Development tasks include: develop team Level 4 Requirements; design operational procedures; support development of the Flight Operations Plan; and develop contingency plans.

7.8.10.7 Engineering Analysis Segment

This effort provides the following operational functions: performance assessment, trend analysis, and calibration analysis for SS engineering subsystems and detailed planning and sequencing of SS engineering subsystem activities. This effort also includes post-launch engineering flight software maintenance and maintenance and operation of any SS engineering test-beds.

7.8.10.8 DSMS Service Segment

A DSMS service is work performed by the service providing system (i.e., the Deep Space Mission System [DSMS]) using one or more tools, facilities, or people that produces mission and science operations results for a user.

7.8.10.9 Mission Operations Module V&V

Planning and leading the execution of MOM-level verification and validation activities. This includes integrating and testing the trained personnel, using operational procedures, with the GDS hardware and software in the MOM operational facility. Objectives of the testing include validation of the readiness of the MM to conduct the engineering operations of the SS.

7.8.11 Science Operations Module

The Science Operations Module (SOM) includes science data processing, science data management and transfer to permanent archive, instrument operations, and science planning functions.

7.8.11.1 Science Operations Module Systems Engineering

The systems engineering efforts needed to coordinate the combined efforts of engineering and science disciplines needed to deliver the SOM and operate the PROMETHEUS 1 instrument payload and manage the mission data produced by the payload. Provide science liaison between the instrument/ payload Principal Investigators (PIs) and Project operations engineers. This work includes, for example: providing science clarification of instrument/ payload operations requirements and evaluating designs and operational plans to ensure that science return is maximized.

7.8.11.2 Investigation A

This effort is for development of the operational capabilities of science investigation A and execution of operations of science investigation A.

7.8.11.3 Investigation B

This effort is for development of the operational capabilities of science investigation B and execution of operations of science investigation B.

7.8.11.4 Investigation C

This effort is for development of the operational capabilities of science investigation C and execution of operations of science investigation C.

7.8.11.5 Investigation X

This effort is for development of the operational capabilities of science investigation X and execution of operations of science investigation X.

7.8.11.6 Science Operations Module V&V

Technical lead for the SOM Verification and Validation: This effort includes planning and leading the execution of SOM-level verification and validation activities and support of the planning of GS-level V&V activities. This includes integrating and testing the trained personnel, using operational procedures, with the GDS hardware and software in the SOM distributed operations facilities. Objectives of the testing include validation of the readiness of the SOM to operate the payload instruments.

7.8.12 Ground System V&V

Planning and leading the execution of GS-level verification and validation activities. This includes integrating and testing the trained personnel, using operational procedures, with the GDS hardware and software in the operational facility. Objectives of the testing include validation of the readiness of the GS to operate the SS.

7.8.12.1 GS V&V

Technical lead for GS Verification & Validation: This effort includes preparation of GS V&V Plan, preparation of procedures for and execution of GS V&V exercises and ORTs (in cooperation with GS Training Engineering), preparation of reports of results of exercises and ORTs. Scope of some of the exercises and ORTs include SS in ATLO and SS simulators and test beds in order to validate the readiness of the GS to operate the SS.

7.8.12.2 GS GDS I&T

Technical lead for GS GDS integration and test: This effort includes preparation of GDS I&T Plan; preparation of test procedures for and leading the execution of GS GDS-level tests; and preparation of test reports.

7.8.13 Space System

The human resources, equipment, data, services, and facilities required to design, develop, assemble, test and deliver the PROMETHEUS 1 Space System that consists of a Reactor Module, a Spacecraft Module, and a Mission Module.

7.8.14 Space System Management & Systems Engineer

This WBS manages and provides leadership for Space System development, architecture study, systems engineering, and control of schedule and cost. Activities include liaison with the Project Office to: define interfaces between the Reactor Module, the Spacecraft Module, the Mission Module, and other Project Systems; define requirements, define space system-level Reactor, Spacecraft, and Mission module tests; support design team meetings and Project reviews; and lead Space System design reviews.

7.8.14.1 Space System Mgmt & Engineer

This work is the technical and management efforts of directing and controlling a totally integrated engineering effort of the Spacecraft. Includes, for example: the effort to

define the system and the integrated planning and control of the technical program efforts of design engineering, specialty engineering, production engineering, and integrated test planning; the effort to transform an operational need or statement of deficiency into a description of system requirements and a preferred system configuration; and the technical planning and control effort for planning, monitoring, measuring, evaluating, directing, and re-planning the management of the technical program. This effort excludes: actual design engineering and the production engineering directly related to the WBS element with which it is associated.

7.8.14.1.1 JPL Space System Management

This work is the technical and management efforts of directing and controlling a totally integrated engineering effort of the Spacecraft. Includes, for example: the effort to define the system and the integrated planning and control of the technical program efforts of design engineering, specialty engineering, production engineering, and integrated test planning; the effort to transform an operational need or statement of deficiency into a description of system requirements and a preferred system configuration; and the technical planning and control effort for planning, monitoring, measuring, evaluating, directing, and re-planning the management of the technical program. This effort excludes: actual design engineering and the production engineering directly related to the WBS element with which it is associated.

7.8.14.1.2 JPL Systems Engineer

Lead the Spacecraft architecture and systems engineering effort. This effort includes, for example, defining inter-subsystem interfaces, defining fault protection guidelines, interfaces, and managing Flight System technical resources. This effort provides for the Flight System Engineer and staff. Documents may include: Flight System Configuration Description document, Master Equipment List (includes Mass and Power Equipment Lists), System Schematics, System I&T Plan, and System Verification Plan.

7.8.14.1.3 JPL Space System Engineering

Lead Space System architecture and Systems Engineering effort. Define inter-module interfaces, define fault protection guidelines, manage Space System technical resources. Documents include: Space System Design Description Document, Master Equipment List (includes Mass and Power), System Schematics, and System Verification Plan. Provide Systems Engineering leadership and support to Mission Operations.

7.8.14.1.3.1 Spacecraft Module Oversight and Direction

This effort is for JPL oversight of Spacecraft Module contracts.

7.8.14.1.3.2 Power Conversion & Heat Rejection Oversight

This effort is for JPL oversight of Power Conversion and Heat Rejection contracts.

7.8.14.1.3.2.1 EP Oversight

JPL oversight of Electric Propulsion contracts.

7.8.14.1.3.2.2 Telecom Oversight

JPL oversight of Telecom contracts.

7.8.14.1.3.2.3 Mechanical Oversight

JPL oversight of Mechanical contracts.

7.8.14.1.3.2.4 Thermal Oversight

This effort is for JPL oversight of Thermal portion of the spacecraft bus contract. Because there is no total system oversight incorporated in any other WBS element, this WBS includes the total interface support required with NASA Centers and other Government agencies in the thermal area, which includes Glenn, Marcshell, Oak Ridge, etc. In addition, provides an interface with contractors. Receivables are thermal inputs from the above described agencies and outputs to support to the development of system thermal architecture, interfaces, supporting the system Configuration Description Document, the Mass Equipment list, Power List/sequencing, etc.

7.8.14.1.3.2.5 AACS Oversight

This effort is for JPL Oversight of AACS.

7.8.14.1.3.2.6 Reaction Control Subsystem Oversight

Review Spacecraft Module Contractor RCS work, including RCS interfaces with other spacecraft subsystems. Participate in all RCS reviews with emphasis on heritage, peer, preliminary design, critical design, and delivery reviews. JPL propulsion system engineers and analysts will verify all critical contractor RCS design choices and analyses.

7.8.14.1.3.2.7 C&DH Oversight

The technical and management efforts of directing and controlling the Integration and Test of the CDH portion of the Project. Includes, for example, review of various element, card, box, and subsystem designs and developments to ensure that the delivered CDH meets performance requirements and function for their intended lifetimes in the environment specified.

7.8.14.1.3.2.8 Power Conditioning & Distribution Oversight

JPL oversight of Spacecraft Module contracts-GRC Support of HV PMAD.

7.8.14.1.3.2.9 Flight Software Oversight

Oversight of all producers of flight software on PROMETHEUS 1 outside of JPL. Includes oversight of FSW, simulation software, and test software. Coordinates the implementation of the Project-level S/W plan and performs CTM duties as identified in the Project Software Plan roles and responsibilities. Covers the entire software development lifecycle.

7.8.14.1.3.2.10 AI&T Oversight

JPL oversight of AI&T activity at system contractor.

7.8.14.1.3.3 Reactor Module Oversight

JPL technical oversight of reactor module in concert with DOE.

7.8.14.1.3.4 JPL Space System Test bed

All activity related to the accommodation, installation, maintenance, and upkeep of the JPL system test bed and associated facilities. Does not include any resources for the use of the test bed. Also does not include any resources related to the fabrication of the elements of the test bed.

7.8.14.1.4 LMA Contract

Lockheed Study Contract.

7.8.14.1.5 Boeing Contract

Boeing Study Contract.

7.8.14.1.6 Northrop Grumman Contract

Northrop Grumman Study Contract.

7.8.14.1.7 GRC Space System Management & Engineering

Includes system trade studies, mission design support, quality/mission assurance, definition/assessment of requirements and interfaces, and contractor oversight for EP, Power Conversion, and Heat Rejection.

7.8.14.1.8 MSFC Space System Management & Engineering

Technical oversight over Space System Integration and Test at MSFC. Level 3 insight in-depth penetration includes daily or weekly involvement to identify and resolve issues. Participate in reviews and technical interchange meetings, perform periodic audits on pre-defined processes, methodically review of space system development, and develop independent models to check and compare vendor data as required.

7.8.14.1.9 DOE Space System Management & Engineering

DOE Space System Management and Engineering includes Federal staff and technical support of DOE labs in oversight of the Reactor Module contractor and on-site support for Reactor Module integration with the space reactor power system.

7.8.14.2 Space System Assurance

The technical and management efforts of directing and controlling the Space System Assurance aspects of the Project. Includes, for example: design, development, review and verification of practices and procedures intended to ensure that the delivered flight system and instruments/payloads meet performance requirements and function for their intended lifetimes. Excludes: Mission and Product Assurance efforts at partners/subcontractors other than a review/oversight function and the direct costs of environmental testing.

7.8.14.2.1 Space System Assurance Mgmt & Engr.

Mission Assurance management for the Reactor Module, Spacecraft Module, and Mission Module and their interfaces. Coordinates within the technical disciplines.

Provides assessment to the Project Mission Assurance Manager and oversees tasks within each of the modules.

7.8.14.2.2 Environmental Engineering

Lead, manage, and provide Environmental Engineering for the Project, including Thermal, Vibration, Acoustic, Natural Space Environments and Electro-Magnetic Compatibility/ Electro-Magnetic Interference (EMC/EMI); Magnetic Cleanliness, test monitoring, etc. Excludes costs of system Environmental Testing. Deliverables: Environmental Requirements Document, Radiation Control Plan, Thermal Analyses/Assessments, Radiation Analyses Completion Statements, Spacecraft radiation model, etc.

7.8.14.2.3 Electronic Parts Engineering

Electronic Parts Engineering oversight of contractor-built spacecraft to ensure proper parts selection, test, and evaluation for flight hardware.

7.8.14.2.4 Reliability Engineering

Lead, manage, and provide Reliability design and analysis support to Project elements at JPL and at partners/subcontractors (as applicable). Includes performing or reviewing Electronic Parts Stress Analyses, Circuit Worst Case Analyses, Interface Failure Modes and Effects Criticality Analyses (FMECAs), Single Event Effects (SEE) analyses on spacecraft electronics; Fault Tree analyses, probabilistic Risk Assessments; review of Problem Failure Reports (PFRs), etc.

7.8.14.2.5 Materials & Processes

Materials & Processes will resolve issues pertaining to M&P and will review and approve Materials Identification & Usage Lists (MIUL) submitted by JPL or contractors for payloads and the spacecraft. M&P will support Project reviews, MMR, and provide assessment of Inspection Reports, PFRs, waivers, and GIDEP alerts, as needed.

7.8.14.2.6 Quality Assurance HW & SW

Hardware Quality Assurance oversight of system contractor (Spacecraft Module) includes JPL and resident QA to ensure proper QA processes are selected and used for flight hardware. Includes Vendor Surveys, Procurement QA support, and resident QA travel costs. Software Quality Assurance oversight of contractor-built spacecraft to ensure proper SQA processes are selected and used for flight hardware.

7.8.14.2.7 Contamination Control

Lead, manage, and coordinate the Contamination Control (CC) effort for the Project. Includes contamination oversight to spacecraft contractor and payload providers. Excludes support to detailed contamination analysis or CC program development, support to Planetary Protection effort, requirements verification, interface documentation, and support to thermal vacuum bake-outs.

7.8.14.3 Planetary Protection Technology

Ensure that the Project meets all NASA planetary protection requirements. Includes, for example: drafting of the required documentation to obtain a PP category for the Project from the NASA Planetary Protection Officer (PPO); performing the necessary analyses, modeling, documentation, and reviews to meet PP requirements through PP launch approval; and reviewing of final PP reports prepared by industrial partners/subcontractors.

7.8.15 Reactor Module

The human resources, equipment, data, services, and facilities required to develop, test, and deliver an integrated Reactor Module that meets the Spacecraft Module and Mission Module requirements. The Reactor Module includes the nuclear reactor, reactor instrumentation and control, reentry shield, and associated radiation shielding for the other modules. The Reactor Module will deliver the required thermal energy to the Spacecraft Module. Includes: breadboards, brassboards, STMs, EMs, Proto-Flight Models (PFMs), spares, and necessary ground tests.

7.8.15.1 Reactor Module Mgmt & Sys Engr

Manage and provide leadership for Module development, and control schedule and cost (i.e. PEM responsibilities). Includes liaison with the Project Office to: define interfaces between the Reactor Module and Spacecraft Module; define requirements; define and perform Module-level tests; support design team meetings and Project reviews; lead Module and Segment design reviews; attend selected component and assembly design reviews. Personnel includes: Manager; Deputy (if any), Lead System engineer; and administrative support. Documents include: Summary Work Agreement and materials for Monthly Management Reviews. Lead and perform overall Module design so that it meets Module requirements and integrates with the Spacecraft Module. Includes, for example: reviewing and approving segment / subsystem specs and maintaining current module performance specifications. Excludes: Module-level support to ATLO.

7.8.15.2 Reactor Module Integration, Assembly and Test

All effort associated with the assembly, integration, and test of the Reactor Module. Includes but is not limited to full ground tests, zero power critical tests, and sub-critical tests. Also includes all subsystem/segment support required for this level of IA&T.

7.8.15.3 Reactor Module Safety & Assurance

All safety and assurance activities related to the Reactor Module.

7.8.15.4 Reactor Module Testing & Eval

The direct effort related to the use of prototype, production, or specifically fabricated hardware/software for Reactor Module development purposes. In addition, this includes the effort required for the design and production of testbeds, models, and instrumentation to support the system-level test program. Excludes all direct effort related to test articles that are complete units.

7.8.15.5 Reactor Module Test Facilities

The effort and expense of designing, building, or upgrading special test facilities required for performance of the various developmental test necessary to prove the design and reliability of the Reactor Module. Excludes operational expenses of new or existing facilities.

7.8.15.6 Reactor Module Support Equipmentt

The design/build or procurement effort for all equipment needed to support the design and construction of the Reactor Module.

7.8.15.7 Reactor Core & Reflectors Segment

Design and fabrication of the reactor core, including the reflectors. Excludes all direct effort associated with Module- and System-level integration and test.

7.8.15.8 Primary Heat Exchanger Segment

The design and fabrication of the primary heat transfer segment. Responsible for coordinating with power conversion areas in 3.3.2. Excludes all direct effort associated with Module and System-level integration and test.

7.8.15.9 Radiation Shield Segment

Responsible for the design and build of the main reactor shield on the spacecraft. This does not include local shielding or the vault. Excludes all direct effort associated with Module- and System-level integration and test.

7.8.15.10 Reactor instrumentation & Control Segment

Design and build all instruments and control systems for monitoring and controlling the reactor. Excludes all direct effort associated with Module- and System-level integration and test.

7.8.15.11 Aeroshell & Superstructure Segment

Responsible for the design and build of the re-entry aeroshell and the support structure that holds the reactor in place. Excludes all direct effort associated with Module- and System-level integration and test.

7.8.15.12 Government Reactor Module Items

All Government technology tasks related to the development of the reactor, shield, or associated technologies, including GFE.

7.8.16 Spacecraft Module

The Spacecraft Module serves as a platform for carrying mission-oriented equipment in space to the mission destination(s) to achieve the mission objectives. It includes a single Spacecraft Module with elements such as: structure; power; attitude determination and control; avionics; other equipment. Also includes all design, development, and production efforts to deliver the completed Spacecraft Module for integration with the Reactor Module and the Mission Module.

7.8.16.1 S/C Module Mgmt & System Engr

Manage and provide leadership for module development, schedule and cost. Includes, for example: providing liaison with the Project to ensure the interfaces between module and Space System are defined, requirements defined, and module-level tests performed; supporting design team meetings and Project reviews; leading subsystem design reviews; and attending selected component and assembly design reviews. Includes Manager, Deputy (if any), Lead System Engineer and administrative support. Lead and perform overall module design and analysis so that it meets its requirements and integrates with the Space System. Includes, for example: generating subsystem test plans, reviewing and approving module / segment specs, resource allocations, and maintaining current module performance specifications. Excludes module support to ATLO. This WBS element includes all Contractor efforts in supporting the Space System and Project Design Teams, Reactor Module and Mission Module Interface discussion, Project Review/meeting support and similar management and system engineering efforts.

7.8.16.1.1 Spacecraft Module Mgmt

All leadership and management activities related to the delivery of a fully integrated and tested Spacecraft Module.

7.8.16.1.2 Spacecraft Module System Engineering -(Contractor)

Lead Spacecraft Module architecture and Systems Engineering effort. Define inter-segment interfaces, define fault protection guidelines, manage Spacecraft Module technical resources. Documents include: Spacecraft Module Description document, Master Equipment List (includes Mass and Power), System Schematics, Electrical Interface Control Drawings, and System Verification Plan.

7.8.16.1.3 Spacecraft Module Assurance

Mission Assurance management and implementation, including Electronic Parts, Radiation Test, Reliability Analysis, Environments, Quality Assurance, and S/W Quality Assurance. Includes all workforce and associated costs

7.8.16.1.4 Reactor-Power Converter System Design

Responsible for coordinating the interface between the reactor and the power conversion system.

7.8.16.2 Power Conversion & Heat Rejection Segment

The complex of equipment (power conversion equipment, primary heat rejection subsystem, and boom), data, services, human resources, and facilities required to develop, produce, test and deliver an integrated segment that meets the requirements, including management, systems engineering, and segment Integration and Test. Includes breadboards, brassboards, STMs, EMs, PFMs and spares. Excludes all direct effort associated with integrating the segment into the Space System.

7.8.16.2.1 Power Conversion & Heat Rejection Management and System Engineering

Manage and provide leadership for subsystem development, schedule and cost (i.e., PEM / Cognizant Engineer [COG-E] responsibilities). Includes, for example: providing liaison with Project to ensure the interfaces between subsystem and Space System are defined, requirements are defined, and subsystem-level spacecraft tests are performed; supporting design team meetings and Project reviews; leading subsystem design reviews; and attending selected component and assembly design reviews. Includes PEM, Deputy PEM (if any) and administrative support. Lead and perform overall subsystem design and analysis so that it meets its requirements and integrates with the Space System. Includes, for example: generating subsystem test plans, reviewing and approving component / assembly specs, slosh analysis, plume impingement analysis, and maintaining current subsystem performance specifications. Excludes subsystem engineering support to ATLO. Documents include: a Work Agreement, Functional and Detailed Requirements, and Interface Control.

7.8.16.2.2 Brayton Power Converter Subsystem

Design and fabrication of the Brayton power converter. Excludes all direct effort associated with the integration and testing of this subsystem in the Space System.

7.8.16.2.3 Heat Rejection Subsystem

Design and fabrication of the heat rejection system. Does not include mechanical and structural elements in support of the heat rejection system. Excludes all direct effort associated with the integration and testing of this subsystem in the Space System.

7.8.16.2.4 Boom Subsystem

Design and build of the deployable boom that supports the radiators in the heat rejection system. Excludes all direct effort associated with the integration and testing of this subsystem in the Space System.

7.8.16.2.5 Power Conversion & Heat Rejection Assembly, Integration and Test

All effort associated with the assembly, integration, and test of the Power Conversion and Heat Rejection Segment. Includes all subsystem support required for this level of IA&T.

7.8.16.3 Electric Propulsion Segment

The complex of equipment (power and control units, ion engines, propellant feed system, propellants tanks, and structure), data, services, human resources, and facilities required to develop, produce, test, and deliver an integrated segment that meets requirements, including management, systems engineering, and segment Integration and Test. Includes breadboards, brassboards, STMs, EMs, PFMs and spares. Excludes all direct effort associated with integrating the segment into the Space System.

7.8.16.3.1 Electric Propulsion Mgmt & Sys Engr

Manage and provide leadership for subsystem development, schedule, and cost (i.e., PEM / Cognizant Engineer [COG-E] responsibilities). Includes, for example: providing liaison with the Project to ensure that the interfaces between subsystem and Space System are defined, requirements defined, and subsystem-level spacecraft tests

performed; supporting design team meetings and Project reviews; leading subsystem design reviews; and attending selected component and assembly design reviews. Includes PEM, Deputy PEM (if any) and administrative support. Lead and perform overall subsystem design and analysis so that it meets its requirements and integrates with the Space System. Includes, for example: generating subsystem test plans, reviewing and approving component / assembly specs, slosh analysis, plume impingement analysis, and maintaining current subsystem performance specifications. Excludes subsystem engineering support to ATLO.

7.8.16.3.2 Ion Engine Subsystem

Develop procurement specifications / Statement of Work (SOW) for and procure ion thruster subsystem and components. Develop final drawing package and assembly procedures and support major reviews. Build, assembly, and acceptance test of thruster subsystem engineering models and flight hardware. Provide engineering model and flight hardware development with development tests and risk management efforts. Provide configuration control of thruster subsystem components. Excludes all direct effort associated with the integration and testing this subsystem in the Space System.

7.8.16.3.3 EP Power & Control Subsystem

The design and build of the power processing and control equipment necessary to support the electric propulsion.

7.8.16.3.4 EP Propellant Feed Subsystem

The design and build of all equipment needed to store, process, and deliver the EP propellant.

7.8.16.3.5 Hall Thruster Subsystem

Develop procurement specifications / Statement of Work (SOW) for and procure hall thruster subsystem and components. Develop final drawing package and assembly procedures and support major reviews. Build, assemble, and acceptance test thruster subsystem engineering models and flight hardware. Provide engineering model and flight hardware development with development tests and risk management efforts. Provide configuration control of thruster subsystem components. Excludes all direct effort associated with the integration and testing of this subsystem in the Space System.

7.8.16.3.6 Reaction Control Subsystem

Design, develop, procure, and integrate components; acceptance test; and deliver to ATLO the Reaction Control Subsystem (RCS) of the Spacecraft Module

7.8.16.3.7 EP Assembly, Integ & Test

All AI&T activities related to the EP subsystem.

7.8.16.4 Bus Segment

The complex of equipment (power conditioning and distribution equipment, command and data handling equipment, attitude, articulation and control equipment, reaction control equipment, cabling, bus structure, inspection cameras, mechanical devices, telecom equipment, and bus thermal control equipment), data, services, and human resources and facilities required to develop, produce, test, and deliver an integrated segment that meets requirements, including management, systems engineering, and segment Integration and Test. Includes breadboards, brassboards, STMs, EMs, PFMs, and spares. Excludes all direct effort associated with integrating the segment into the Space System.

7.8.16.4.1 Bus Management and System Engineering

All leadership and management activities related to the delivery of a fully integrated and tested bus segment.

7.8.16.4.2 Attitude & Articulation Control Subsystem

The complex of equipment, data, services, human resources, and facilities required to develop, produce, test, and deliver an integrated guidance, Navigation, and Control (GN&C) subsystem that meets requirements. Includes breadboards, brassboards, STMs, EMs, PFMs, and spares. Excludes all direct effort associated with integrating the subsystem into the flight system.

7.8.16.4.3 Command and Data Handling Subsystem

The complex of equipment, data, services, human resources, and facilities required to develop, produce, test, and deliver an integrated subsystem that meets its requirements. Includes breadboards, brassboards, STMs, EMs, PFMs, and spares. Excludes all direct effort associated with integrating the subsystem into the flight system. Refer to STDWBS Element 06.10 for flight software that performs command processing, sequencing, telemetry processing, and on-board data management.

7.8.16.4.4 Power Conditioning & Distribution Subsystem

This is the WBS for PC&D. The elements of the WBS are 400-V PMAD, 400 V to 28 V down converter and 28-V Power System electronics. Major receivables are the DSA PSE design. Major deliverables are one flight unit integrated and tested delivered to ATLO, a set of spare hardware integrated and tested, and 3 EM units (one for developmental and performance testing, one used for flight qualification, and one set assembled to a test bed and delivered to ATLO).

7.8.16.4.5 Bus Structure Subsystem

Provide the primary structure and other structural elements to the Spacecraft. Includes, for example: the structural platform(s) to which subsystems, instruments, and payloads are attached; booms and pedestals (other than those delivered with instruments/payloads), solar panel substrates, and assembly fasteners.

7.8.16.4.6 Bus Thermal Control Subsystem

The complex of equipment, data, services, human resources, and facilities required to develop, produce, test, and deliver an integrated subsystem that meets its requirements. Includes breadboards, brassboards, STMs, EMs, PFMs, and spares. Excludes all direct effort associated with integrating the subsystem into the flight system.

7.8.16.4.7 Bus Mechanical Devices Subsystem

"This WBS Element encompasses the Mechanical Devices Subsystem. The MechDev S/S produces the actuators, bearings, and associated hardware that performs appendage launch restraint, deployments, and articulations.

Delivery of Thermal Louvers is also covered under this WBS Element. "

7.8.16.4.8 Telecom Pointing Platform Subsystem

The complex of equipment, data, services, human resources, and facilities required to develop, produce, test, and deliver an integrated subsystem that meets its requirements. Includes breadboards, brassboards, STMs, EMs, PFMs, and spares. Excludes all direct effort associated with integrating the subsystem into the flight system.

7.8.16.4.9 S/C Cabling Subsystem

This WBS Element is responsible for the design and fabrication of the Flight System Cabling.

7.8.16.4.10 Telecom Subsystem

The complex of equipment, data, services, human resources, and facilities required to develop, produce, test, and deliver an integrated subsystem that meets its requirements. Includes breadboards, brassboards, STMs, EMs, PFMs, and spares. Excludes all direct effort associated with integrating the subsystem into the flight system.

7.8.16.4.11 Optical Nav Camera Subsystem

Develop and deliver to industry a gimbal-mounted, redundant, optical navigation camera to industry. The unit is to be protected against the radiation requirements specified for the mission.

7.8.16.4.12S/C Self Inspection Camera Subsystem

Develop and deliver to industry 5 non-radiation hardened cameras for viewing all Spacecraft and Mission Module deployments and thermal radiators.

7.8.16.4.13Environmental Monitoring Subsystem

Government effort associated with the design and fabrication of environmental monitoring equipment and sensors on the spacecraft. Excludes all direct effort associated with integrating the subsystem into the Space System

7.8.16.4.14Bus Assembly Integration and Test

The human resources, equipment, data, services, and facilities required to integrate and test the Bus Assembly.

7.8.16.5 Launch Vehicle Adapter Segment

The design and fabrication of a mission-unique launch vehicle adapter to join the main structure of the spacecraft with the launch vehicle. Excludes all direct effort associated with integrating the segment into the Space System.

7.8.16.6 Spacecraft Module Assembly, Integration and Test

All effort associated with the assembly, integration, and test of the Spacecraft Module. Includes all subsystem support required for this level of IA&T.

7.8.16.7 Spacecraft Module Test and Evaluation

The direct effort related to the use of prototype, production, or specifically fabricated hardware/software for spacecraft development purposes. In addition, this includes the effort required for the design and production of testbeds, models, and instrumentation to support the system-level test program. Excludes all direct effort related to test articles that are complete units.

7.8.16.8 Spacecraft Module System Level Software Segment

The complex of software to provide for the Space System a software operating system, health monitoring, command and control, telemetry, and data storage and handling. Includes, for example: software required to interface, command, and control instruments and payloads and the various subsystems of the Space System. Excludes science investigative and other software delivered with the instruments/payloads.

7.8.16.9 Spacecraft Module Test Facilities

The effort and expense of designing, building, or upgrading special test facilities required for performance of the various developmental test necessary to prove the design and reliability of the Spacecraft Module. Excludes operational expenses of new or existing facilities.

7.8.16.10 Gov't Spacecraft Module Items

Government technology and development items during Phase A/B. Includes miscellaneous GFE items.

7.8.16.10.1 Gov't Rad Hard Technology

Government (NASA, DOE) Technology development of Rad Hard Technology during Phase A.

7.8.16.10.2 Govt' Deep Space Electronics

Government (NASA, DOE) Technology development of Deep Space Electronic Technology during Phase A.

7.8.16.10.3 Govt' Power Conversion & Heat Rejection

Government (NASA, DOE) Technology development of Power Conversion and Heat Rejection Technology during Phase A.

7.8.16.10.4 Gov't Electric Propulsion

Government (NASA, DOE) Technology development of Electronic Propulsion Technology during Phase A.

7.8.16.10.5 Gov't Telecom

Government (NASA, DOE) Technology development of Telecom Technology during Phase A.

7.8.16.10.6 Gov't Mechanical GFE

This WBS Element provides Government Furnished Equipment (GFE) to the Space System contractor. GFE Deliverables are: fully redundant deployment actuators (Dual Drive Actuator) for appendages and NSI pyrotechnic squibs.

7.8.17 Mission Module

The human resources, equipment, data, services, and facilities required to design, develop, assemble, integrate, and test the Mission Module. Includes the instruments provided for experimental and science data gathering. It also includes instrument support components such as Software, Scan Platform Assembly, and Turntable Assembly.

7.8.17.1 Mission Module Management and System Engineering

Manage/coordinate Request For Proposal / Announcement of Opportunity (RFP / AO) (as applicable). Function as the Contract Technical Managers (CTMs) for instrument/MM contracts. Provide the primary interface between the Project and instrument/MM providers. Define and manage the requirements and interfaces between the instruments/SMM and the Flight System. Includes, for example: the mechanical and electrical Interface Control Documents; Configuration Control; and Risk Management.

7.8.17.2 Mission Module Mgmt & Engr.

Manage/coordinate RFP / AO (as applicable). Function as the CTMs for instrument/MM contracts. Provide the primary interface between the Project and instrument/MM providers. Includes, for example: MM Manager and a Deputy MM Manager (as needed). MM System Engineering and staff are responsible for interfaces between all instruments & MMs and the Flight System. This includes design and engineering for the mechanical, optical, electrical, and thermal interfaces.

7.8.17.2.1 Mission Module Mgmt

All leadership and management activities related to the delivery of a fully integrated and tested Mission Module.

7.8.17.2.2 Mission Module System Engineering

Lead Mission Module architecture and Systems Engineering effort. Define interfaces between instruments and MM and between MM and S/C; define fault protection guidelines; and manage MM technical resources. Documents include: Mission Module Description document, Master Equipment List (includes Mass and Power), System Schematics, and System Verification Plan. Provide Systems Engineering leadership and support to Mission Operations.

7.8.17.2.3 Mission Module System Mechanical Engineering

Lead and perform overall mechanical SS design so that it meets SS and Mission Module requirements and integrates with the Module. Includes generating SS test plans; reviewing and approving component / assembly specifications; and maintaining current SS performance specifications. Excludes SS engineering support to ATLO. Documents include a work agreement; functional and detailed requirements; ICDs for mechanical, electrical, and information interfaces; RFPs; POs; associated documentation such as NSPARs; design specifications; drawings; AIDS; as-built parts documentation; test plans and test Procedures for SS functional and performance tests; HRCR package prior to delivery to ATLO; and test reports from functional tests prior to ATLO.

7.8.17.3 Bus Mounted instruments Segment

The equipment provided for special purposes in addition to the normal equipment integral to the spacecraft. Includes, for example: experimental and scientific data gathering equipment placed on board and mounted directly to the bus.

7.8.17.3.1 Mgmt & System Engr

Function as the Contract Technical Managers for bus-mounted instrument/payload contracts. Provide the primary interface between the Project and bus-mounted instrument/payload providers.

7.8.17.3.2 Bus Mounted instruments

All activities related to the design, fabrication, and integration of the flight instruments to be mounted on the bus.

7.8.17.3.3 Bus Mounted instrument Mechanical Subsystem

The human resources, equipment, data, services, and facilities required to develop, test, and deliver an integrated mechanical SS that meets SS and Mission Module bus requirements. Includes breadboards; brassboards; STMs; EMs; PFMs; and spares. Excludes all direct effort associated with integrating the SS into the Mission Module.

7.8.17.4 Scan Platform Segment

The design and build of a gimbaled scan platform that meets the science requirements for AACS and instrument accommodation.

7.8.17.4.1 Scan Platform Mgmt & System Engineering

Function as the Contract Technical Managers (CTMs) for bus-mounted instrument/payload contracts. Provide the primary interface between the Project and the scan platform instrument/payload providers. Includes for example: Payload Manager and Deputy, as needed. Define and manage the requirements and interfaces between the bus-mounted instruments/payloads and the Flight System. Includes, for example: mechanical, thermal, and electrical ICDs; configuration control; and risk management. Provide engineering support expertise as needed in areas such as stray light analysis, contamination analysis, parts qualification, and parts radiation testing.

7.8.17.4.2 Scan Platform instruments

All activities related to the design, fabrication, and integration of the flight instruments to be mounted on the scan platform.

7.8.17.4.3 Scan Platform Mechanical Subsystem

All activities related to the design and fabrication of the mechanical system required to gimbal the scan platform.

7.8.17.4.4 Scan Platform Cabling Subsystem

The design and build activities related to accommodating potential payloads on the scan platform via power and a data cabling.

7.8.17.4.5 Scan Platform instrument Assembly, Integ &Test

This task has been merged into WBS 3.4.9, per agreement with Dave Lehman and Div. 31.

7.8.17.5 Turntable Segment

The design and build of a rotating turntable that meets the science requirements for AACS and instrument accommodation.

7.8.17.5.1 Turntable Mgmt & System Engineering

Function as the Contract Technical Managers (CTMs) for bus-mounted instrument/payload contracts. Provide the primary interface between the Project and the turntable instrument/payload providers. Includes, for example: Payload Manager and Deputy, as needed. Define and manage the requirements and interfaces between the bus-mounted instruments/payloads and the Flight System. Includes, for example: mechanical, thermal, and electrical ICDs; configuration control; and risk management. Provide engineering support expertise as needed in areas such as stray light analysis, contamination analysis, parts qualification, and parts radiation testing.

7.8.17.5.2 Turntable instruments

All activities related to the design, fabrication, and integration of the flight instruments to be mounted on the turntable.

7.8.17.5.3 Turntable Mechanical Subsystem

All activities related to the design and fabrication of the mechanical system required to rotate the turntable.

7.8.17.5.4 Turntable Cabling Subsystem

This WBS Element is responsible for the design and fabrication of the Flight Turntable Cabling.

7.8.17.5.5 Turntable Assembly, Integ & Test

This task has been merged into WBS 3.4.9, per agreement with Dave Lehman and Div. 31.

7.8.17.6 Auxiliary Science Package Segment

All activities related to the design, fabrication, and integration of the auxiliary science payload. Also includes all activities related to the accommodation of the payload in the Space System.

7.8.17.7 Instrument Purge Segment

Design, develop, procure, and integrate components; acceptance test; deliver to ATLO the Science Instrument Purge Subsystem (SIPS) of the Spacecraft Module and its associated Ground Support Equipment (GSE). Provide round-the-clock purge service to each instrument at their various locations from the time of initial need until launch (T-0).

7.8.17.8 Optical Comm. Accommodation Segment

All necessary design and fabrication activities required to accommodate the optical communication technology test. Including: cabling, thermal, and structure accommodations.

7.8.17.8.1 Optical Com Subsystem

7.8.17.8.2 Optical Comm. Accommodation

Implementation of optical telecommunication pointing and control algorithms, device driver software, and processing of commands and telemetry interfaces to the optical telecom element. Includes the monitoring of engineering data for out-of-bounds conditions and triggering fault responses, as necessary.

7.8.17.9 Mission Module Software Segment

Design, code, and test of Flight Software to accommodate instruments and payloads at the Flight System software interface. Includes, for example: basic command and control signals to the instrument/payload software, timing signals, and data receipt and storage. Excludes software internal to the instrument/payload for its operations, health, and scientific data gathering.

7.8.17.10 Mission Module Assembly, Integration and Test

All effort associated with the assembly, integration, and test of the Mission Module. Includes all subsystem support required for this level of IA&T.

7.8.17.11 Mission Module Test Facilities

Prepare/upgrade SAF at JPL for Mission Module assembly, integration, and test.

7.8.18 Space System Assembly, Integration and Test

The human resources, equipment, data, services, and facilities required to integrate and test the Reactor Module, Spacecraft Module, and the Mission Module into the PROMETHEUS 1 Space System. Includes, for example: mechanical and electrical assembly; functional testing and environmental testing; and transportation/logistics support. Includes all subsystem support required for this level of IA&T.

7.8.19 Space System Test Facilities

The effort and expense of designing, building, or upgrading special test facilities required for performance of the various developmental test necessary to prove the design and reliability of the Spacecraft Module. These may include Plum Brook, etc. Also may include the costs of new facilities at JPL for Mission Module testing or costs of JPL facility upgrades that the Project might have to support (for example, replacement of lamps in the Solar Vacuum Chamber). Excludes operational expenses of existing facilities.

7.8.19.1 GRC

The construction, maintenance, and operations of all facilities at GRC needed to support the test activities for the Space System.

7.8.19.2 MSFC

The construction, maintenance, and operations of all facilities at MSFC needed to support the test activities for the Space System.

7.8.19.3 Plum Brook

The construction, maintenance, and operations of all facilities at Plum Brook needed to support the test activities for the Space System.

7.8.19.4 JPL

The construction, maintenance, and operations of all facilities at JPL needed to support the test activities for the Space system.

7.8.20 Launch System

The construction, maintenance, and operations of all facilities at GRC needed to support the test activities for the Space System.

7.8.21 Launch Systems Management & Systems Engineering

Overall project management and systems engineering efforts required for the planning, directing, and controlling of the Launch Systems required to accomplish the goals of the PROMETHEUS 1 Project.

7.8.22 Launch Vehicle

The resources (labor, equipment, data, services, etc) required to develop the launch vehicle and associated systems required for integration with the Space System.

7.8.23 Launch Site Facilities

The resources (labor, equipment, data, services, etc) required to develop the facilities and support equipment required to support launch site processing of the Space System. Excludes operational expenses of existing facilities.

7.8.24 Launch System V&V

The resources (labor, equipment, data, services, etc) required to integrate, verify, and validate the Launch System.

7.8.25 Launch Services

The resources (labor, equipment, data, services, etc) required to receive, process, integrate, and launch the PROMETHEUS 1 mission.

7.8.26 Launch Site Nuclear Operations – DOE

Provides resources for planning, process development, design, assurance of safe and reliable operation, provision of necessary authorizations, construction of facilities, provision of specialized support equipment to conduct nuclear operations at the launch site to support PROMETHEUS 1 Project objectives.

7.8.26.1 Launch Site Nuclear Operations Mgmt & Sys Engr

This WBS element includes costs of planning, developing, and managing the facility for KSC activities related to the ATLO of the flight reactor module (FS-1). Includes developing the site requirements for testing of FS-1, developing all procedures needed to support the testing, and administrative support staff.

7.8.26.2 Launch Site Nuclear Operations Integration, Assembly & Test

The human resources, procurements and other operations required to receive, inventory, safeguard and load fuel, prepare and condition coolant surfaces and make RM closures (e.g., welds), loading reactor coolant and other operations involving special nuclear materials including physics testing, mechanical and electrical acceptance testing of the RM prior to its movement to the 100-K facility for final spacecraft integration.

7.8.26.3 Launch Site Nuclear Operations Safety and Assurance

Provides all safety, security, safeguards, and assurance activities related to nuclear operations at the launch site.

7.8.26.4 Launch Site Nuclear Operations Facilities

This includes the cost of detailed design, construction, modification, and maintenance of the facilities needed to house and test the nuclear fuel and the reactor module at KSC. It also includes the cost for S&S at the 100-K facility during the time the reactor is in that facility. It does not include any cost to modify the 100-K facility to handle the fueled reactor.

7.8.26.5 Launch Site Nuclear Operations Support Equipment

The design/build or procurement effort for all equipment needed to support the ATLO testing of the reactor module and reactor fuel at KSC. It will not include the cost of design, construction, or licensing of the cask to transport the nuclear fuel since this is included in a different WBS. Also, the test reactor module to be used for training is FSM-2; this will be costed in a different WBS.

7.8.27 Project Systems Assembly, Integration and Test

The human resources, equipment, data, services, and facilities required to integrate and test the Space System with the Launch System and the Mission Operations System.

7.8.28 Space System - L/V Assembly, Integration and Test

This work provides labor and travel associated with on-site support of post-ship checkout, any Launch Vehicle interface compatibility tests, and integration of the Space System with the Launch System. This work includes: time period from arrival of the Space System at the Launch site to Launch + 30 days. Includes all subsystem support required for this level of IA&T.

7.8.29 Ground Support to Space Systems and Launch Vehicle I&T

This work provides all resources needed to support integration and test activity with the Grounds System.

8 Hubble Robotic Servicing & De-Orbit Mission (HRSDM)

8.1 De-Orbit Module

8.1.1 Project Management

8.1.2 Systems Engineering

8.1.3 Integration and Test

8.1.4 Flight Software

8.1.5 Ground Systems

8.1.6 S/C

8.2 Ejection Module

8.2.1 Management

8.2.2 Systems Engineering

8.2.3 Electrical Systems

8.2.4 Mechanical Systems

8.2.5 Thermal Systems

8.2.6 Guidance Navigation and Control

8.2.7 Flight Software

8.2.8 Integration and Test

8.2.9 Ground Systems Development

8.2.10 Flight Operations

8.3 Robot Grapple Arm

8.3.1 Robot Contr.

8.3.2 Arm Contr.

8.4 Payload

8.4.1 COS

8.4.2 WFC3

8.4.3 Latches/SSE

8.4.4 RSUs

8.4.5 Tools

8.4.6 Fabrication

8.5 ELV

8.5.1 KSC Contr.

8.6 Systems Engineering & Mission Integration and Test

8.6.1 CHAMP Core

8.6.2 Multi-Discipline Engineering Support

8.6.3 Multi-Discipline Integration and Test

8.6.4 Training/SIM Development

8.7 Management & Program Control

8.7.1 Contr. Support

8.8 Ground Systems and Operations Support

8.8.1 Service Mission Ops Preps

8.8.2 Ops Verification

8.8.3 Ground Systems Integration and Test

8.8.4 Flight Software

9 Centennial Challenge

To be provided

10 ESMD Headquarters Support

This element provides for the work associated with the general programmatic and technical support to the ESMD Headquarters office. Activities relative to miscellaneous support contractor support, contract administration, education and public outreach, NASA Peer Review services, printing and graphic support, telecommunication equipment and operation, ODIN computers and support services and bank card procurement provisions and support are captured in this element.

APPENDIX A System of Systems Tier Template

(A) represent any number 1-n, which is to identify a given spiral development activity.
For example : Spiral 1 : 4.1
Spiral 2 : 4.2
Spiral 3 : 4.3
Spiral n : 4.n

4.A System of Systems I

4.A.1 System Management

This element encompasses all the work required to organize, plan, lead, and control all facets of the activities required to develop Constellation System of Systems. This effort includes leading the overall Constellation business and administrative management functions, including establishing and maintaining an earned value management (EVM) system for determining budget requirements, conducting analysis and controlling allocation; all activities associated with developing and executing the acquisition and procurement strategy; workforce requirements and utilization; integrated master plan and schedule (IMP/IMS) development, execution, and assessment; and information management and dissemination. Documentation includes an Investment Plan based on WBS gap analysis/Industry concept studies.

4.A.1.1 Program/Project Management

TBD

4.A.1.2 Business Management

This element encompasses all coordination activities associated with the acquisition strategy, System of Systems authorizations, budget analysis and allocation, system workforce utilization, and integrated program assessment measurement.

4.A.1.3 Information Management

This element encompasses the effort required to disseminate required information to System of Systems stakeholders. Additionally, this element encompasses the effort required to develop a Constellation communication and reporting plan, as well as respond to unexpected requests for information.

4.A.1.4 Administrative

This element encompasses the effort required to facilitate the System of Systems management operations, including human resources, staff assignments, and security, etc.

4.A.1.5 Requirements Management

This element provides support to manage programmatic cost, schedule, and scope trade-offs. Scope includes the assurance of the consistent application of program requirements across the System of Systems elements.

4.A.1.6 Acquisition Management

This element encompasses efforts required to develop an acquisition strategy plan for Constellation. Additionally, solicitation planning, solicitation development, source selection, contract administration, and contract closeout efforts are included here.

4.A.1.7 Comprehensive Risk Management

This element encompasses efforts required to prioritize technical and programmatic risks associated with the System of Systems. Technical risks are recommended by the systems engineering team, including identification, analysis, planning, and costs. Work includes approval and funding of risk mitigation plans, tracking of mitigation progress, and status reporting to system stakeholders.

4.A.1.8 Supportability and Integrated Logistics Support Management

This element encompasses all efforts for engineering and support considerations necessary to assure the effective, sustainable, and economical support of a system for its total life cycle. This element is an integral part of all other aspects of system acquisition and operation. Work includes development of supportability strategy and establishing and leading a management team, with representation from system integrated logistics support activities.

4.A.2 System of Systems Engineering

This element includes the work to implement the processes necessary to separate elements of the System of Systems into manageable work elements, and to allow those elements to be readily integrated into a final product that meets its intended capability. Scope includes the work to ensure the proper tools, procedures, and processes are applied across all the lower tier elements with the System of Systems. These processes describe the work for requirements formulation, decomposition and prioritization, configuration and data management, risk assessment, system definition, system integration, integrated logistics support, and integrated operations. Scope also includes the work to implement spiral, modular transformation with development in spirals, along with evolving modular components and technology maturation, for inclusion in future spirals. The requirements include technical requirements and programmatic requirements. The effort also includes decomposition of requirements for technologies that must be matured prior to system acquisition. Scope also includes the work to perform operations studies and analyses, producing operations metrics across system elements, developing operations life cycle cost assessments, and developing, integrating, and assessing integrated operations schedules. Scope also includes the work to guide the generation of lower tier system elements with focused, prioritized requirements based on a common operational concept.

4.A.2.1 Engineering Management

The scope of this element includes the work required to provide full life cycle technical program management for the Exploration Systems overall system architecture, definition, and engineering functions. Scope includes leadership of the System of systems engineering team; establishment of the standards and specifications that apply to the System of Systems and all lower tier work (if not already established at the Agency or

Directorate level); management of the System of systems action-item list; provision of a technical management liaison to internal and external customers of the System of Systems; the resolution of technical issues in this element; and provision of management authority for resolution of lower-tier systems technical issues. Scope also includes the work to ensure management rigor focused on scheduled priorities, technical performance, and cost performance in this element and oversight for lower-tier system elements. Scope encompasses the work necessary for organizational implementation for Integrated Discipline Teams (IDT) (defining how IDTs will be setup, executed and dissolved); the development of an Integrated Management (or Master) Plan (IMP) and an Integrated Master Schedule (IMS) (identifies key events, milestones, reviews, all integrated technical tasks, and risk reduction activities); and other progress measurement tools to track major reviews progress, programmatic technical performance, develop lessons learned, and the recording of accomplishments. It includes the work associated with reduction in total ownership cost planning and support (cost control, cost reduction, invest to modernize planning, and assurance that life cycle costs are implemented as co-equal to performance in acquisition). Scope includes the work to exercise final authority over all lower-tier system level studies and other decisions. Documentation products include, but are not limited to, a Systems Engineering Management Plan (SEMP), Integrated Discipline Team Manual (IDTM), project technical review plans, and systems engineering management reports.

4.A.2.2 Requirements Definition

This element provides for an analysis of mission needs, overarching operations concept, System of Systems requirements, and the documentation of the resultant requirements. It comprises the work required for requirements analysis, including trade studies and documenting requirements specifications. It includes the work required for the successive refinement of decomposition (partitioning) of System of Systems requirements into allocated and derived requirements, appropriately assigned to lower-level system element products. Scope includes the work to document verification and compliance requirements at the System of Systems level. Scope also includes the derivation and tracking of key performance parameters and operational thresholds and objectives. Scope also includes the work required for the definition, execution, and documentation of trade studies for desired and practical trade-offs among stated requirements (user requirements, design, program schedule, and functional, performance, and life-cycle costs). Scope also includes trades at various levels of functional or physical detail to support requirements, functional decomposition/allocation, and design alternative decisions, or as specifically designed to support the decision needs of the systems engineering process. This element scope also includes the work required to integrate all system element requirements, such that all requirements decompose down and integrate up to provide total traceability, and includes the work to assure that the final integrated architecture meets interface requirements and is balanced (performance balanced with cost, schedule, and effectiveness requirements). This element also contains the work to support an assessment of design-related changes in requirements for System of Systems capabilities. The assessment involves near-term increment requirements to be formulated in an interactive manner to the system definition (design) effort until the Preliminary Design Review (PDR) milestone. Generally speaking, the requirements development effort for

that particular increment is complete after PDR and requirements resulting after PDR are deferred to future increments for the particular system. Additional scope includes the work to capture decision-database information for decision rationale traceability and documentation products including, but not limited to, a Systems Requirements Document (that contains performance, operational, functional, evaluation criteria, interface, and associated environmental requirements) for each system in the System of Systems architecture; a refined Concept of Operations for the architecture; and an Interface Requirements Document for the System of Systems.

4.A.2.3 Configuration and Data Management

This element captures the efforts for managing the overall configuration of the System of Systems flight and ground systems throughout the development, implementation, and operations. Scope involves the planning, organization, integration, support, and monitoring functions for tracking changes, conducting change board reviews, and maintaining configuration documentation, to include decision support data. This element includes management of document configuration at the System of Systems level and establishes policy and standards for the systems-level configuration management activities.

4.A.2.4 Risk Identification and Analysis

This element includes the overarching identification and analysis for risk reduction at the Constellation level. These processes shall be applied to the technical, schedule, and cost aspects of the System of Systems. It includes insight and oversight in the planning and conducting of project/demonstrations for the identification of risk, and trade analysis to reduce the risk of the overall program. Additionally, this element includes training in, and execution of, specialized risk identification techniques that are performed on an as-needed basis for Constellation activities. Also includes identification of risk mitigation task requirements, resources, and schedule for System of Systems and system element levels.

4.A.2.5 System Definition

This element includes the work to identify the assembled set of interdependent systems and their associated physical, functional, and/or operational contribution to the System of Systems architecture required to meet the System of systems requirements. The system definition at this WBS element is generally limited to the identification of the physical/functional systems and their associated functional, operational roles in the overall architecture. Any required components that exist only to integrate the physical or functional capability of the composite System of Systems are defined in detail at this element. This element contains the work to oversee the design of the systems that comprise the System of Systems and ensures that physical and functional interfaces are maintained between physical products and functional processes. This element contains the work to monitor lower-tier design activities and guide the implementation of procedures necessary to concurrently develop products and their associated processes. Work includes participation in lower-tier design reviews to represent the integrated vision for functional, physical, and operational considerations in lower-tier product design and associated manufacturing, test, and support processes that meet the intended need.

System analyses include operational feasibility studies, effectiveness analyses, environmental assessments, long-term logistics support assessments, technology assessments, industrial base assessments, life cycle hardware, and software feasibility assessments based on design models and resultant overall systems risk identification. Scope includes continual iteration and maturing depth of analyses as the system progresses through its life cycle to support sound decisions and to assure safety, readiness, and continual reductions in the cost of operations. Scope also includes the work to capture decision-database information for decision rationale traceability. Documentation products include, but are not limited to, a System of Systems design document (SDD) that contains an operational, physical, and functional concept for the architecture the System of systems (describes the physical, operational, and functional interdependence of the systems in the System of Systems architecture).

4.A.2.6 System Integration

This element encompasses the effort required to plan, monitor, and certify the verification, validation, and acceptance of the Constellation elements to ensure that they meet the requirements and can execute the mission objectives as intended. Scope involves assurance that all supporting system elements are ready to support end-to-end tests, definition of key system test plans for completeness and ability to meet goals, and review of key test scripts for timing and order of execution of command sequences. The validation, verification and acceptance work is planned for each level of the "system" as it is "reintegrated in design" from the bottoms-up (the right half of the systems engineering "V"). This work includes verification that the entire life cycle requirements are met, interfaces requirements are met and controlled, interoperability requirements are addressed, each requirement has a corresponding verification item and method necessary to perform the verification identified, and the necessary test plans are available to conduct the verification, validation, and acceptance (VV&A). Scope includes the work to support the development of the Test and Evaluation Master Plan (TEMP) and the Operational Test and Evaluation Plan.

4.A.2.7 Integrated Logistics Support

A composite effort of all the engineering, supportability analysis, planning, and support considerations necessary to assure the effective, sustainable, and economical support of the system of systems for their life cycle. It is an integral part of all other aspects of system acquisition and operation. It also provides oversight and insight to Constellation systems and elements. Deliverables include an initial Integrated Logistics Support Program Plan (ILSPP) that will include the System of systems Supportability Strategy and will address the factors of ILS to be considered early in system design continuing through operations support and retirement.

4.A.2.8 Integrated Discipline Team (IDT) Activity

The scope of work for the Integrated Discipline Team (IDT) is to collect, integrate and communicate, Integrated Product Team (IPT) issues, risks, and technology, needs to Exploration Systems Mission Directorate (ESMD) chief engineer or delegated authority. This scope also covers performing in-house portion of the systems integration function. They support system integration during the request for proposal/source evaluation board

process. They also provide a systems integration function until an award of a Systems Integration contract is made.

The IDT is a collection of technical expertise grouped around particular engineering disciplines or mission focus, where as an Integrated Product Team (IPT) is made of cross-functional disciplines grouped to focus on an individual product. IDTs provide discipline-specific support to Project Constellation, and the development programs within it, with an independent reporting path through Project Constellation's System Engineering & Integration (SE&I) Office. The teams are staffed with joint membership including prime contractors and independent experts (government civil service, support contractor, and FFRDC) and are distributed "in the field" to provide a mechanism for organizing center support to Constellation programs.

The IDTs are responsible for the Constellation Level 2 (L2) requirements, standards, issues, technology development requirements, and other product needs generated the Constellation Chief Systems Engineer. They are also responsible for "task-level" assignments and cross-cutting assignments and the integration of the various actions across all of the IDTs. Products will also feed into the risk management and performance review process.

The IDTs will serve as a direct resource for the Constellation Chief Systems Engineer (CSE) and will provide technical and programmatic guidance as directed. They will be mission focused, discipline oriented teams tasked with delivering technical expert guidance limited in scope only by the request from the CSE. IDTs shall ensure the compatibility of discipline requirements across systems and across spirals. They shall also ensure "checks and balances" by independently reporting discipline recommendations to the SE&I office and the independent technical authorities as requested. The following demonstrates IDT scope responsibilities and deliverables.

- Cross-element integration
- Cross-element Interface definition and management
- Cross-program human resource allocation issues
- Cross-program facility resource allocation issues
- Cross-element verification planning
- Commonality and standards
- Technology needs identification and performance assessment/evaluation
- Risk Management
- Requirements Development and Validation
- Issue resolution
- Technical Baseline Management

4.A.2.8.1 Systems Engineering & Integration Team

The SE&I IDT is to provide the Constellation Systems Engineering and Integration Office (CSEIO) with the plans and processes needed to successfully execute and integrate projects. This team implements the plans and processes on behalf of the CSEIO. They support the release of RFPs, lead decomposition of level 1 requirements to the level 2 requirements, and architecture technology gap filler requirements. They are responsible

for developing document products such as, systems engineering management plans, integratied master schedules, risk management plans and reports, configuration and data management plans, document trees with dictionary, human rating plans, design reference missions, functional models, level 2 requirements, environmental qualifications and test requirements, interface requirements, natural environments definition for design, major program reviews and reports, lessons learned management plans, master verification plans and technology requirements.

4.A.2.8.2 Constellation Systems Analysis Team

This element encompasses the work for developing various study plans and guidelines. This team also performs analyses in cycles with several studies performed within a cycle. The studies are based on prior studies and a prioritized list of trade tree options. Other work involves RFP support, analyses to support requirements development, analyses to verify and validate requirements, and design reference architecture formulation.

4.A.2.8.3 Cost Engineering Team

This elements encompasses the work necessary to provide consistent, credible, an supportable life cycle cost estimates. The activities which support this effort are organizing, benchmarking, data collecting, innovating methods, and process execution.

4.A.2.8.4 Safety & Mission Assurance Team

This element encompasses the work necessary to develop and document safety and reliablility technical requirements; SM&A programmatic requirements and processes; and levy those requirements on contractors through acquisition processes. This work is to document and baseline selected safety and mission assurance plans; derive and develop S&MA technical requirements; document S&MA processes and programmatic requirements; and develop and implement acquisition products such as DRDs, SOW, etc. This effort provides the following example of document products: S&MA plans; system safety plans; hazard anlaysis and reporting requirements and guidelines; failure modes and effects analysis requirements and guidelines; Reliability and Maintainability plans; quality assurance plans; and quantitative risk analysis requirements and guidelines.

4.A.2.8.5 Operations Team

This element describes the work required to support the development of the level 2 concept of operations and the operations plan.

4.A.2.8.6 Human Centered Team

This element describes the work for defining crew requirements, oversee design cycles to ensure compliance eith these requirements, define and validate functional allocations between crew, ground and machine based intelligence, and oversee the design and standaradization of user interfaces and crew roles and procedures on space flight vehicles, surface habitability modules, EVA suits, and lunar/mars surface transportation vehicles. Other efforts include human interface design, optimimazation, and standardization. The team also participates in appropriate trade studies with the goal of

optimizing decisions regarding human-machine functional allocation and the design of user interfaces to support those allocations.

4.A.2.8.7 Structural, Mechanical, Materials & Manufacturing

This element describes the work necessary to support Constellation Systems in several key areas. These include: RFP development and program planning, requirements development and technology requirements. Other work includes procurement support, independent analysis and products, contractor technical insight, IPT/contractor deliverables and IDT management planning and operations.

4.A.2.8.8 Command, Control & Communications

This element describes the work necessary to support the development of Command, control, Communications and information (C31) support plan (DR41) and the electromagnetic compatibility/interference (EMC/EMI) control plans.

4.A.2.8.9 Ground Infrastructure

This element describes the scope of work for supporting end item procurement, providing integrated products in support of RFP development, evaluation and selection. The focus of ground infrastructure IDT team is to ensure integration of ground infrastructure, including capabilities and assessments across all ground elements for consistency, standardization, and commonality. Products associated with these efforts include but are not limited to, Ground Infrastructure Capabilities, Assessment, and Development Plans, Ground Infrastructure Readiness and Development plans.

4.A.2.8.10 Aerosciences & Flight Mechanics

This element describes the scope of work needed to provide support the end item development through reviews. The efforts in this area are time phased, based upon draft and baseline release of documents leads. We will be providing major support and input in several areas where the AFM discipline inputs are required. The AFM IDT is especially focusing on areas where flyability and survivability of the vehicle system must be ensured. Flight regimes include ascent, on-orbit, entry, landing, and most importantly, abort scenarios. Requirements for these regimes will be defined and validated working with other IDTs and contractors.

4.A.2.8.11 Propulsion & Fluids

This element provides the scope of work associated with support provided by the Propulsiona and Fluids team. The efforts provided by this team include but are not limited to, development of the government's cross system technical insight into the systems under the end item development systems; identify cross cutting systems integration issues, understand the issue, evaluate proposed resolution, and develop recovery plans; perform cross system risk identification, reporting tracking and mitigation planning for safety, performance, cost and schedule; provide technical insight into design, developments, tests, verifications, and validations; ensure compatibility of discipline requirements across systems and throughout the spiral development process; assist in level II requirements decomposition; support review board membership; develop

and evaluate the technology needs associated with the discipline; and support RFP preparation.

4.A.2.8.12 Power Systems

This element provides the scope of work associated with support provided by the Power Systems team. These efforts focus on maintaining interoperability, robustness and commonality throughout the various power systems developed across the mission needs. The efforts provided by this team include but are not limited to, development of the government's cross system technical insight into the systems under the end item development systems; identify cross cutting systems integration issues, understand the issue, evaluate proposed resolution, and develop recovery plans; perform cross system risk identification, reporting tracking and mitigation planning for safety, performance, cost and schedule; provide technical insight into design, developments, tests, verifications, and validations; ensure compatibility of discipline requirements across systems and throughout the spiral development process; assist in level II requirements decomposition; support review board membership; develop and evaluate the technology needs associated with the discipline; and support RFP preparation.

4.A.2.8.13 Computer, Software, and Automation

This element describes the scope of work associated with insight and ensurance of technical issues as it relates to computer, softare and automated systems design. This effort provides systems engineering functions with a focus on computer and software systems. The team performs analyses in support of these functions such as a FMECA vs FMEA study, a modular computing architecture study, a space computing platforms study, autonomy and automation requirements for projects, ISHM for projects, computing and software fault tolerance, and software reuse, compatibility and interoperability.

4.A.2.8.14 Robotics

TBD

4.A.3 Safety and Mission Assurance

Concerning this system of system element, this component includes the technical and management efforts for developing and implementing, across the Office of Exploration Systems, requirements for the safety and mission assurance function in the disciplines of safety, environmental protection, reliability, maintainability, supportability assurance, quality assurance, and operations. This effort also includes an independent review and assurance function over the design, development, testing, review, and certification/verification of Constellation system of systems. This element covers the areas of Management and Administration along with Business Management for the Constellation element system of systems.

4.A.3.1 Management and Administration

Concerning Constellation, this component is to lead and manage the overall safety and mission assurance (S&MA) effort and provide the primary S&MA interface to other

enterprise divisions. Includes support of necessary agreements (Annual Operating Agreement (AOA), Memorandum of Agreement (MOA)), resource plans (Program Operating Plan (POP)), schedules, and procedures to guide and direct the S&MA functions through all phases of the initiative, from design through disposal. This effort provides sufficient review for certification of flight worthiness. Management and Administration will act as a liaison between organizations and between contractors and organizations to provide smooth communications and to facilitate distribution and review of deliverables, and to coordinate exchange of information. Management and Administration will schedule or participate in scheduling of major reviews, programmatic meetings, presentation of analytical results, and other such meetings that directly affect Constellation projects. Management and Administration will coordinate and facilitate S&MA-related conferences to cover all aspects of safety, mission assurance, and risk of projects.

4.A.3.1.1 Business Management

This element encompasses all S&MA coordination activities associated with the acquisition strategy, systems authorizations, budget analysis and allocation, system workforce utilization, and integrated program assessment measurement. It includes reviewing and providing support and budget for Analysis of Alternatives (AOA) and MOAs, and providing metrics to demonstrate status and progress.

4.A.3.2 Safety and Mission Assurance (S&MA) Integration

Concerning Constellation, this element includes the technical and management efforts necessary for establishing and integrating S&MA functions across all systems required to complete an exploration mission. Includes development of necessary plans, establishment of adequate safety, maintainability, and reliability design requirements, and procedures to guide and direct the integrated mission assurance functions through all phases of the initiative, from design through disposal. Ensures continuity across all lower-level S&MA functions and approval of top-level enterprise S&MA elements by supporting the risk management process; ensures development of S&MA process requirements, contract Request for Proposals (RFP), Statements of Work (SOW), Data Requirements Documents (DRD), and Source Evaluation Boards (SEB). This element also includes planning of the S&MA tasks, along with developing and assessing requirements for stated systems. This element covers the areas of external assessment along with S&MA for the Constellation element System of systems. Also includes providing Hazard Analysis, Risk Assessment, Failure Mode Assessment, and other analytical investigations of safety and quality, or reviews of analysis provided by the contractor(s). S&MA will participate in the determination of flight readiness and be signatory to Certificate of Flight Readiness (COFR).

4.A.3.3 External Assessment

For Constellation, this element includes review, consideration, and communication of independent assessments. Groups that provide independent oversight and technical support, such as the Aerospace Safety Advisory, Independent Program Assessment Office, etc., will be supported in their efforts and their reports will be given full consideration. Independent technical authority will be encouraged and fully supported.

4.A.3.3.1 Safety and Mission Assurance Panels

This element includes the technical and management efforts necessary for the operation of Programmatic S&MA Panels. Personnel and technical expertise will be provided to all S&MA board, committees and panels. These supporting functions will be coordinated and facilitated by this element. Such boards include but are not limited to panels such as: the Safety Review Panel (SRP), the Reliability, Maintainability and Supportability (RMS) Review Panel, and the Ground Safety Review Panel.

4.A.3.3.2 RMS Review Panels

Concerning RMS Review Panel, this element includes the technical and management effort necessary to ensure the overall safety and protection of flight and ground personnel, general public, flight/ground hardware, software, and facilities through all phases of the initiative, including insight/oversight of contracted efforts. It includes the implementation of requirements for and ensuring the adequacy of: safety plans, hazards analyses, safety non-compliance disposition, safety assessment, reports, and reviews of flight/ground/planetary hardware and software element, and operations plans and range safety. Also includes the coordination of government contractor safety teams. Element includes development of Constellation-level hazard analysis guidelines and Constellation integrated hazard analyses (HA) based on inputs from Constellation element (HA)s. This element also includes implementation of requirements for each mission dictating safe handling and usage of radioactive elements (where applicable), and safety to the mission due to exposure to radiation in space and while on lunar and planetary surfaces. A human factor strategy for safety of flight and ground personnel will be developed and refined into guidelines. Natural environments such as Micro-meteoroid Orbital Debris (MMOD) will be evaluated.

4.A.3.4 Safety, Health and Environment Assurance (SHEA)

This element includes the efforts necessary for providing occupational (industrial) safety and health and environmental assurance function for all aspects of the Constellation initiative. This effort includes providing for a regulatory assurance function related to Occupational (Industrial) Safety and Health and Environmental Protection on Earth. Specific components of this element which will be considered and planned for include human factors of occupational safety. This element also includes development and review of guidelines to be established to ensure that the public and ground and flight crews are as safe as possible in executing their duties and assignments. SHEA will: ensure that toxicity, fire, explosion, and propellant safety have all been considered and plans are in place to keep the risk at minimum; develop proper techniques for dealing with hazardous or emergency situations such as fire, explosion, or propellant mishaps; develop a system, in accordance with Agency guidelines, for properly reporting and investigating mishaps of any nature involving the initiative; develop trending and metrics for mishaps in order to track and develop corrective action strategies; develop proper emergency response plans and teams to deal with mishaps and emergencies, whether personnel or equipment; and establish a plan for steps to deal with contingencies and proper implementation of plans. This element also includes activities to ensure that all Constellation element

System of systems are compliant with the National Environmental Protection Act (NEPA).

This element will also promote general safety awareness among all employees; develop programs to make employees more aware of safety hazards in the work area; ensure proper certification and instruction for employees who use specialized or hazardous equipment or procedures, such as lifting, laser operation, and radiation safety; and evaluate vulnerability assessment and trending for status and for contingency response planning.

Additionally, this element covers the areas of Occupational (Industrial) Safety, Occupational Health, and Environmental Protection for the Constellation element System of systems.

4.A.3.4.1 Occupational (Industrial) Safety

This element includes the insight function necessary for ensuring that Constellation elements across the Constellation programs comply with federal or state Occupational Safety regulations.

4.A.3.4.2 Occupational Health

This element includes the insight function necessary for ensuring that Constellation elements across Constellation programs comply with federal or state Occupational Health regulations.

4.A.3.4.3 Environmental Protection

This element includes the insight function necessary for ensuring that Constellation elements across Constellation programs comply with federal or state environmental regulations. This element also includes the development of plans and requirements to ensure that all Constellation element system of systems are compliant with the NEPA.

4.A.3.5 Reliability and Maintainability

This element includes the technical and management efforts necessary for assuring Reliability and Maintainability for all aspects of the initiative. This element will: establish methods and guidelines for determining hardware reliability using some combination of analysis, test, demonstration, or similarity; consider and plan for human reliability in all aspects of their function; establish backup plans for the failure of the human element; ensure that a maintenance concept is supportive of the Mission Concept of Operations; and ensure that logistics elements responsible for the Integrated Logistics Support Plan include integration of reliability and maintainability elements. Additionally, this element covers the areas of Reliability and Maintainability for the Constellation element system of systems.

4.A.3.5.1 Reliability

This element includes the tasks necessary to ensure the overall reliability of the systems. This element will implement requirements for, and ensure adequacy of, reliability

analyses, reliability/risk assessments/tradeoffs, coordination between government and contractor reliability teams, and requirements compliance. Element includes development and maintenance of Integrated Constellation Reliability documents, including Integrated Reliability Policy; Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL) Guidelines; Probabilistic Risk Assessment (PRA) guidelines and analysis; Problem Reporting and Corrective Actions (PRACA) Guidelines; and Integrated FMEA/CIL Design Verification. This element will also: develop a strategy for gathering and using trending analysis in reliability consideration; factor reliability into all aspects of hardware limits and life such as, but not limited to, FMEA/CIL and Limited Life Requirements and Tracking; establish Problem Reporting and Corrective Action system for Constellation; and recommend design changes to improve hardware/software reliability.

4.A.3.5.2 Maintainability

This element includes the review/performance of those tasks necessary to ensure the overall maintainability of the systems consistent with the Mission Concept of Operations. This element will implement requirements for, and ensure adequacy of, maintainability analyses, maintenance/replacement tradeoffs, coordination between government and contractor maintainability teams, and requirements compliance. The work includes development and maintenance of the Integrated Constellation Maintainability assurance documents, including Integrated Constellation Maintainability Policy, Maintenance Concept, Maintainability Program Plan, and Maintainability Design Criteria Document. This element also includes maintainability demonstrations, ensuring that a maintenance data collection system is established to allow trending analysis and consideration of limited life items, and their disposition and effect on a program. This element will also recommend design changes to improve hardware/software maintainability.

4.A.3.6 Product Assurance

This element includes the technical and management efforts necessary for assuring establishment, management, and maintenance of the overall quality system for system hardware and software. This element also includes: implementing requirements for, and ensuring adequacy of, product assurance requirements/plans; performing inspections and audits; monitoring quality; and maintaining oversight of the procurement, design review, manufacturing, testing/verification, and validation efforts, including provisions for insight/oversight of contracted efforts for all aspects of the initiative. This element also includes: ensuring adequacy and implementation of product assurance requirements/plans; performing inspections and audits; monitoring quality; and maintaining oversight of the procurement, design review, manufacturing, testing/verification, shipping and handling, and validation efforts, including provisions for insight/oversight of contracted efforts for all aspects of the initiative.

This element will also: establish a strategy for how to enfold into the assurance models such things as hardware and software certification, verification, validation, qualification, and an acceptance data package; establish a risk management plan, to include PRACA, trend analysis, and Government-Industry Data Exchange Program (GIDEP) data.

This element will also assist in formulating an acquisition strategy that incorporates aspects of product assurance.

Additionally, this element covers the areas of Electrical, Electronic, and Electromechanical (EEE) Parts for the Constellation System of systems.

4.A.3.6.1 Electrical, Electronic, Electromechanical (EEE) Parts

This element includes the technical and management efforts necessary for assuring establishment, management, and maintenance of parts control programs. This element will also ensure adequacy and implementation of the establishment and maintenance of parts lists, review and issuance of alerts/advisories, parts control, part test/qualification/screening programs, parts testing activities, and test reporting, including provisions for insight/oversight of contracted efforts for all aspects of the initiative. This element also includes development and maintenance of the Constellation EEE Parts Program Plan.

4.A.3.6.2 Materials and Processes Product Assurance

This element includes the technical and management efforts necessary for assuring establishment, management, and maintenance of processes for materials and processes assurance/certification. This element is to ensure that Material(s) Identification and Usage Lists (MIUL), and Material(s) Usage Agreements (MUA) are done properly and adequately reviewed and approved across all Constellation System of systems.

4.A.3.7 Software Assurance

This element includes the effort necessary to ensure that software developed meets overall S&MA requirements for the protection of flight and ground personnel, general public, flight/ground hardware, software, and facilities through all phases of the initiative, including insight/oversight of contracted efforts. This element will also ensure adequacy and implementation of software safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of flight/ground/planetary software element, operations plans, and range safety. Includes development and maintenance of the Constellation Software Quality Plan

This element also includes: the technical and management efforts necessary for ensuring that mission requirements and system design changes are carried forward across software life cycle phases of the operations system; the management and technical interfaces, provision of products and artifacts, and responses to issues necessary to support Independent Verification and Validation (IV&V) throughout the life cycle; and establishing that requirements of certifying software, performing trending analysis, and establishing reliability and tracking quality will be used in demonstrating software assurance.

4.A.3.8 Operations Safety and Mission Assurance

This element includes the technical and management efforts necessary for assuring performance of flight (both aviation and spaceflight)/ground/surface operations

(including both in-flight and surface EVA) processes and procedures. This element will ensure adequacy and implementation of operational procedures, flight rules, checklists, and guidelines, including pre- and post-operation checkout with respect to known hazards and system failure modes. Participation in operations includes the assessment of changes to flight rules, crew procedures, etc., for the purpose of maintaining the validity of hazard and failure controls. This element also provides monitoring of real-time operations. This element will also: establish plans for contingencies at all points in mission; ensure adequate policy for test, flight, ground and mission operations; give proper consideration of orbital debris generation and its potential affect and plan contingencies; review trend analysis of in-flight problems and anomalies and provide appropriate input for corrective action; and ensure that proper range safety procedures and policies are implemented.

4.A.3.9 Human Rating and Crew Survival

This element provides for the effort necessary to certify human–rated space flight systems and to ensure the use of all available mechanisms, including abort and escape, safe haven, emergency egress, and search and rescue for human space flight systems. It also determines if the program has implemented all design efforts, and established, assessed, and documented agency requirements for an acceptable life cycle cumulative probability of safe crew and passenger return for all missions over the life of all Constellation programs and projects. The element also determines if all human–rated flight systems are designed in compliance to agency Human-Rating Requirements for Space Flight Systems to preclude a catastrophic safety risk to the flight crew**.**

The element will also: establish human performance criteria and system usability requirements to ensure crew safety; certify space flight systems reliability and safety by test and analysis at the integrated system level prior to the first flight with humans on board; develop and implement a formal process to maintain the human-rating certification for the life of the program; complete structured usability testing with crew involvement to verify that the system design meets the required human performance criteria during system operation, maintenance, and control; test, verify and validate the performance, security, and reliability of all critical software across the entire flight envelope, as well as mission functions, modes and transitions; develop and utilize a testing facility with a flight-equivalent avionics test-bed operating in a real-time, closed-loop test environment; test ground software on the computer platforms that will be used to support flights; and confirm the integrity of the software design and testing process through independent verification and validation methods. Critical software is any software component whose failure or unanticipated performance could lead to the loss of the space flight system or crew and passengers. This includes the flight software as well as ground software that can affect flight safety.

4.A.3.10 Nuclear Safety

This element includes the effort necessary to ensure the overall safety and protection of flight and ground personnel, the general public, flight/ground hardware, software, and facilities through all phases of the initiative when nuclear material is present. This includes a nuclear risk management evaluation. This element will ensure adequacy and implementation of safety plans, hazards analyses, safety non-compliance disposition,

safety assessment, reports, and reviews of nuclear hardware elements and operations plans, and compliance with Federal law and regulations. This also includes support to the Inter-agency Nuclear Safety Review Panel (INSRP). This element will implement policy prescribed in the National Environmental Protection ActSee Appendix B Tier 2 Constellation Functional Work Template.

4.A.4 Reserved

4.A.5 Integration and Test

This element includes all effort of technical and functional activities associated with the design, development, and production of mating surfaces, structures, equipment, parts, materials, and software required to assemble the tier 3 equipment (hardware/software) elements into a tier 2 mission equipment (hardware/ software) as a whole and not directly part of any other individual tier 3 element. The scope may include the development of engineering layouts, determination of overall design characteristics, and determination of requirements of design review; the set up, conduct, and review of testing assembled components or subsystems prior to installation; the detailed production design, producibility engineering planning (PEP), and manufacturing process capability, including the process design development and demonstration effort to achieve compatibility with engineering requirements and the ability to produce economically and consistent quality; inspection activities related to receiving, factory and vendor liaison; design maintenance effort; quality planning and control; tooling (initial production facilities, factory support equipment) including planning, design, and fabrication; administrative engineering; the joining or mating and final assembly of tier 3 equipment elements to form a complete prime mission equipment when the effort is performed at the manufacturing facility; integration of software (including loading and verification of firmware); and conduct of production acceptance testing. This scope excludes all systems engineering/program management and system test and evaluation which are associated with the overall system.

4.A.5.1 Analysis and Design

This element encompasses all the work required for integrated vehicle design, analysis, and modeling; acquisition support, mass properties analysis; loads and dynamics analysis; thermal analysis; flight mechanics and performance analysis; and contamination analysis.

4.A.5.2 Test

This element encompasses hardware related activities associated with mockups, vehicle level test hardware, vehicle level development/qualification test operations, vehicle level acceptance test operations. And module level test if applicable.

4.A.5.3 Assembly

This element encompasses all the work required for equipment installation and alignment; major segment mating, and module packaging, if applicable.

4.A.6 Integrated Operations

This element focuses on the integration of the System of systems operations and provides the planning, directing, controlling, and execution of an integrated operations effort to meet System of systems mission objectives. This element encompasses operations integration activities, integrated logistics support, and consolidated operations implementation to support an integrated System of systems mission and provides insight into operations common or multi-use systems to provide a balanced and integrated operation capability. This effort also includes integration of NASA's operational expertise in the design and development of Constellation System of systems focusing the expertise on each system and horizontally across the program to ensure integrated operations capability across the system. The Integrated Operations activity also includes assessing the schedule and cost control for operation and sustainment of the mission operations activities throughout the system life cycle and producing operations metrics to ensure the most efficient and effective operations throughout the life of the system

4.A.6.1 Operations Management

This element encompasses all the work required to manage and administer all facets of the operations activities at the System level. It leads the operations team in the early planning of ground, mission, and surface operations; integrated support to designing the ground, mission, and surface operations system; and conducting of System ground, mission, and surface operations. Also includes System operations document and processes development (operations implementation plan, mission planning and manifesting processes, etc). It addresses the work necessary to support the Integrated Management (or Master) Plan (IMP) and Integrated Master Schedule (IMS) (identifies key events, milestones, reviews, and all integrated operations tasks) along with other progress measurement tools to track operations performance.

4.A.6.2 Operations Integration

This area performs operations integration across the enterprise system by translating System of systems objectives and requirements into a viable mission operations concept. During the development of the operations infrastructure, this area integrates the System of systems mission and operations planning, processes, tools, facilities and systems to promote and ensure consistency, compatibility, and efficiency across the System of systems. This element will focus on the following:

1. Integration of the system of system operations, and provide balanced and integrated Operations Products to the Program
2. Integrate NASA's Operational expertise in the design and development of the System of systems, focusing the expertise on each system and horizontally across the program
3. Ensure integrated operations capability across the system
4. Assess the schedule and cost control for the development and operation of the operations activities throughout the system life cycle
5. Manage the operations metrics to ensure the most cost efficient operations throughout the life of the system

4.A.6.3 Ground Operations Integration

This element captures the overall ground processing integration and coordination across the elements to ensure commonality and standardization for the System of systems missions. This includes defining, and developing the integrated plans and processes for ground processing activities. Ground Processing includes the activities required to prepare a mission for flight (i.e. vehicle processing; maintenance and refurbishment; assembly, test, and check-out; integrated testing, multi-element integration testing to include end to end testing with satellite communications and ground mission control, launch operations; and recovery operations). This element also captures the coordination of launch site processing ground systems including facilities, support equipment, and check-out equipment. Includes support of systems engineering efforts that define and document the ground, launch, and range operations requirements; plans, procedures, and tools to satisfy requirements; and training, test, and certification plans.

4.A.6.4 Mission Operations Integration

This element provides mission operations integration and coordination across the elements to ensure commonality and standardization for the System of systems missions. This includes defining and developing the integrated plans and processes for flight operations activities. Mission Operations includes the activities required to prepare a mission for flight (i.e. plans, procedures, tools, flight design, and training, test, and certification plans). This activity also supports the coordination of flight operations communication, commanding, controlling, data analysis, and anomaly resolution and contingency planning capabilities. Includes support of systems engineering efforts that define and document the mission operations requirements; plans, procedures, and tools to satisfy requirements; and training, test, and certification plans.

4.A.6.5 Surface Operations Integration

This element captures the overall surface operations integration and coordination across the System of systems to ensure commonality and standardization. Surface operations includes the activities performed on the lunar and planetary surface including system and science operations, servicing, maintenance, repair, handling, surface preparations, and environmental issues (e.g. electrostatic properties of dust).

4.A.6.6 Consolidated Systems Operations

This element captures the integration effort required when two or more systems or their respective elements (CEV, transfer stage, lander, habitat, etc) are supporting a System of systems mission during the planning and execution phase of operations. The activities to be included in this element are mission integration, ground processing, mission operations, and lunar/planetary surface operations. For example the flight planning activities for an on-orbit rendezvous of two space vehicles would be included as a part of this work as well as subsequent execution of the flight operations to support this task. Common and multi-use facilities operations and maintenance activities will be captured in 4.7 and unique element operations will be defined for each element in WBS elements 4.8-4.(n).

4.A.6.6.1 Mission Integration

This element provides the analysis and integration of ground, flight and surface operations planning, preparation and execution for the System of systems through all phases of operations, including the necessary ground facilities, equipment, systems and software. This element ensures that the enterprise mission and operations planning, processes, tools, facilities and systems are implemented efficiently across the enterprise. This element implements the environmental compliance initiatives for ground, flight, and surface operations. Also, included in this element are the definition, preparation, and conduct of mission readiness reviews.

4.A.6.6.2 Ground Operations

This element captures the integrated ground processing operations activities for the System of systems missions. This includes but is not limited to; certification, training, simulation, ground processing operations, and support and disposal through the System of systems life cycle.

4.A.6.6.2.1 Certification

This work includes ground system validation tests to demonstrate capability and readiness to launch System of systems Missions. Includes certification of facilities, support equipment, and personnel, Prepare test plans and provide test reports.

4.A.6.6.2.2 Training and Simulation

This work includes training and certification of ground operations personnel for Exploration Missions. This includes lesson and training material development, software, and simulated flight element hardware, facilities, conduct of training, launch rehearsals, tests and maintenance of test results. Tasks also include preparing plans and producing training reports. The training occur both prior to and during ground processing operations.

4.A.6.6.2.3 Logistics

This element captures the integrated operations logistics activities for the System of systems ground processing operations. Activities included in this element are logistics management and integration, logistics engineering, maintenance and supply support, parts sparing (including flight hardware), government property management, and government furnished services.

4.A.6.6.2.4 Launch Preparation Operations

The technical and management efforts to direct and control the integrated ground operations activity in preparation for and execution of launch site operations in support of System of systems Missions. This includes execution of the activities to prepare the flight hardware for launch, including but not limited to, flight hardware receipt and inspection, maintenance and refurbishment, assembly and checkout, integrated testing, hardware servicing, integration with the launch vehicle, payload processing and integration, and transportation.

4.A.6.6.2.5 Launch Operations

The technical and management efforts to direct and control the integrated ground operations activity in preparation for and execution of launch of System of systems Missions. This includes, but is not limited to, final preparations for launch and launch countdown activities.

4.A.6.6.2.6 Landing and Recovery Operations

This work provides the technical and management efforts to direct and control the integrated landing and recovery operations activities in preparation for and execution of landing and recovery of System of systems Missions. This includes, but is not limited to, recovery and safing of the flight hardware after a mission and transportation to a post-flight processing facility.

4.A.6.6.2.7 Launch Abort and Recovery

The technical and management efforts to direct and control the ground operations activity in preparation for and execution of launch aborts and recovery in support of System of systems Mission components. This includes, but is not limited to, recovery and safing of the flight hardware after a mission and transportation to a post-flight processing facility

4.A.6.6.2.8 Range Operations

This work provides the technical and management efforts to direct and control the range operations activities in preparation of and execution of range operation in support of System of systems Missions. This includes, but is not limited to, supporting hazardous activities at the launch site, launch operations, and landing and recovery operations. This element also includes scheduling the range support in support of Exploration Mission activities.

4.A.6.6.2.9 Retirement/Disposal

The activity associated with planning for and executing the disintegration of the ground processing operations complex and disposal of the associated assets consistent with ITAR and NEPA restrictions.

4.A.6.6.3 Mission Operations

This element consists of a pre-flight planning phase(s) followed by flight operations, which carry out the integrated mission objectives. To accomplish the mission, several launches may be required to place the Constellation systems in space. The pre-flight planning phase includes the mission planning of events and basic crew/flight control team timelines associated with each flight; the flight dynamics design; the crew and flight control team training; development and verification of the flight procedures (nominal and malfunction recovery), flight rules, system schematic, systems supporting documents (systems briefs), command and control tools, and data display and analysis tools. With the pre-mission preparation complete, the flight crew and flight control team are ready to proceed to flight operations execution and accomplish the mission objectives.

4.A.6.6.3.1 Certification

Prepare, coordinate, and conduct integrated mission operations system validation tests to demonstrate the capability and readiness of the mission operations system to operate and support the System of systems missions. Provide the mission operations V&V system engineer a process which assures the integrated mission operations system is ready and capable of safely carrying out its intended purpose. Prepare the test plan and provide test reports.

4.A.6.6.3.2 Training and Simulation

This element provides resources to perform integrated training and certification of crew and operations personnel for the System of systems Missions. This includes lesson and training material development, mock-ups, trainers, simulators, facilities, and supporting software; preparation, planning, and coordination for incorporation of the trainers into the training flow; conduct of operations training, rehearsals, and tests. Tasks also include preparing the operations training plan and producing training reports. Training will occur both prior to and during flight operations

4.A.6.6.3.3 Logistics

This element captures the integrated operations logistics activities for the System of systems mission operations. Activities included in this element are logistics management and integration, logistics engineering, maintenance and supply support, parts sparing (including flight hardware), government property management, and government furnished services.

4.A.6.6.3.4 Flight Design and Flight Planning

This element provides technical and management resources to perform an integrated mission planning process for the System of systems. This element is an integrated process of the flight design responsibilities and the flight plan development. The Flight Design portion includes analysis of launch opportunities, ascent, orbit, rendezvous, and entry / landing in preparation for the execution of a mission. A mission may include multiple launches of crewed and un-crewed elements. The Flight Planning portion of the element includes the integrating and coordinating high-level requirements, tasks, science objectives, ground commanded activities, attitude and pointing requirements, and crew constraints into a cohesive, integrated plan. The task will result in the preparation and publishing of an integrated flight plan. Flight planning will occur both prior to (pre-flight) and during flight operations (re- planning).

4.A.6.6.3.5 Payload Planning

This element provides resources to perform payload planning for the System of systems missions. This includes integrating and coordinating high-level payload requirements, tasks, payload science objectives, payload ground commanded activities, payload attitude and pointing requirements, coordinating activities with Primary Investigators, and providing payload inputs into the crew activity scheduling. Task also includes preparing and publishing various operations integration documents. Payload planning will occur both prior to (pre-flight) and during flight operations (re- planning).

4.A.6.6.3.6 Flight Operations Products and Procedures Development

This element includes all documentation necessary for capturing the operations knowledge of the spacecraft associated with the System of systems integrated missions' activities. These documents include flight rules, nominal and off-nominal (malfunction) response procedures for the flight crew and flight controllers, operations related drawings, spacecraft system briefs, and console operations briefs. This element also includes the software tools and supporting documentation used by the flight control team in their pre-flight assessments for power, life support, thermal, and propulsion. Additional software tools and supporting documentation are developed for ground commanding to the various spacecraft and for supporting spacecraft telemetry display and interpretation applications.

4.A.6.6.3.7 Flight Operations

The technical and management efforts to direct and control the integrated mission operation activities associated with the executions of System of systems mission operations including all activities associated with the flight crew and flight control team support. It includes the efforts to plan and execute the integrated flight operations requirements; using the plans, procedures, tools and training. This activity supports the flight operations of the System of systems missions with communication, commanding, controlling, data analysis, and anomaly resolution and contingency planning capabilities.

4.A.6.6.3.8 Retirement Disposal

The activity associated with planning for and executing the disintegration of the mission operations complex and disposal of the associated assets consistent with ITAR and NEPA restrictions.

4.A.6.6.4 Surface Operations

This element captures the integrated surface operations activities for the System of systems missions. This includes but is not limited to; integrated planning, training, simulation, flight certification, surface system infrastructure and science operations, and support and disposal through the System of systems life cycle.

4.A.6.6.4.1 Certification

This element provides for the preparation, coordination, and conduct of surface operations integrated system validation tests to demonstrate the capability and readiness of the surface operations system to operate and support the System of systems Missions. Provide the surface operations V&V system engineer a process which assures the surface operations system is ready and capable of safely carrying out its intended purpose. Prepare the test plan and provide test reports.

4.A.6.6.4.2 Training and Simulation

This element provides resources to perform integrated surface operations training and certification of crew and operations personnel for the System of systems Missions. This includes lesson and training material development, mock-ups, trainers, simulators, facilities, and supporting software; preparation, planning, and coordination for

incorporation of the trainers into the training flow; conduct of operations training, rehearsals, and tests. Tasks also include preparing the operations training plan and producing training reports. The training occur both prior to and during surface operations

4.A.6.6.4.3 Logistics

This element captures the integrated surface operations logistics activities for the System of systems. Activities included in this element are logistics management and integration, logistics engineering, maintenance and supply support, parts sparing (including flight hardware), government property management, and government furnished services.

4.A.6.6.4.4 Surface Operations Desing and Planning

This element provides technical and management resources to perform an integrated mission planning process for the System of systems. This element is an integrated process of the surface ops design responsibilities and the suface ops plan development. The surface ops design portion includes analysis of excursion opportunities, rendezvous, and etc. in preparation for the execution of a surface mission. A mission may include multiple excursions of crewed and un-crewed elements. The surface ops planning portion of the element includes the integrating and coordinating high-level requirements, tasks, science objectives, commanded activities, communications attitude and pointing requirements, and crew constraints into a cohesive, integrated plan. The task will result in the preparation and publishing of an integrated surface ops plan. Surface ops planning will occur both prior to and during surface operations (re- planning).

4.A.6.6.4.5 Surface Operations Products and Procedure Development

This element includes all documentation necessary for capturing the operations knowledge of the System of systems elements associated with the System of systems missions. These documents include Flight Rules, nominal and off-nominal (malfunction) response procedures for the flight crew and flight operations team, operations related drawings, and surface operations system briefs. This element also includes the software tools and supporting documentation used by the flight control team in their pre-flight assessments and in-flight verifications for power, life support, thermal, and propulsion margins. Additional software tools and supporting documentation are developed for ground commanding to the various Systems of systems surface elements and for supporting associated telemetry display and data interpretation applications.

4.A.6.6.4.6 Payload Planning

This element provides resources to perform integrated payload planning for the surface operations of the System of systems missions. This includes integrating and coordinating high-level payload requirements, tasks, payload science objectives, and payload commanded activities, payload pointing requirements, coordinating activities with Primary Investigators, and providing payload inputs into the crew activity scheduling. Task also includes preparing and publishing various operations integration documents. Payload planning for surface operations will occur both prior to (pre-flight) and during surface operations (re- planning).

4.A.6.6.4.7 Operations

The technical and management efforts to direct and control the integrated surface operation activities associated with the flight crew and flight control team support in their execution of a System of systems mission. It includes the efforts to plan and execute the integrated surface operations requirements using the plans, procedures, tools, and training. This activity supports the surface operations of the System of systems missions with communication, commanding, controlling, data analysis, and anomaly resolution and contingency planning capabilities.

4.A.6.6.4.8 Retirement Disposal

The activity associated with planning for and executing the disintegration of the mission operations complex and disposal of the associated assets consistent with ITAR and NEPA restrictions.

4.A.6.6.5 Communications

This element provides resources for all of the integrated network communications for the System of systems mission during test and operations. This includes ground facilities as well as satellite usageThis element focuses on the integration of the System of systems operations and provides the planning, directing, controlling, and execution of an integrated operations effort to meet System of systems mission objectives. This element encompasses operations integration activities, integrated logistics support, and consolidated operations implementation to support an integrated System of systems mission and provides insight into operations common or multi-use systems to provide a balanced and integrated operation capability. This effort also includes integration of NASA's operational expertise in the design and development of Constellation System of systems focusing the expertise on each system and horizontally across the program to ensure integrated operations capability across the system. The Integrated Operations activity also includes assessing the schedule and cost control for operation and sustainment of the mission operations activities throughout the system life cycle and producing operations metrics to ensure the most efficient and effective operations throughout the life of the system.

4.A.6.7 Ground Support Systems

This element encompasses the work associated with the acquiring or developing of ground support systems and equipment, which are unique or dedicated to the end item of which it is subordinate. This section is intended to capture those physical end items necessary to support the space end item being developed. It includes but is not limited to mobile support structures, test fixtures, handling fixtures, computer control and data acquisition ground support equipment and software used during integration, test and checkout of the space end item.

4.A.6.8 System of Systems End Item

This element encompasses the work associated with the acquiring or developing of the space end item architecture derived from allocated requirements. The physical end item

is the decomposed product of the system architecture to achieve the required mission objectives.

APPENDIX B Systems Functional Work Template

(A) represents any number 1 to n, which is to identify a given spiral development activity.

For example : Spiral 1 : 4.1
Spiral 2 : 4.2
Spiral 3 : 4.3
Spiral n : 4.n

(B) represents any number from 7 to n, which is to identify a given end item physical system to be developed.

For example :		
	SS Ground Support Systems :	4.A.7
	Crew Exploration Vehicle :	4.A.8
	Crew Launch Vehicle :	4.A.9
	Etc. :	4.A.(n)

4.A.B.1 End Item Management Team

This element encompasses all the work required to organize, plan, lead and control the activites needed to establish, plan, and support a prime contract managed by the government.

4.A.B.2 End Item RFP/SEB Support

This element encompasses all the work required to organize, plan, lead and control the activites needed to establish, plan and.support the development of a request for proposal to procure an end item contract. This work also includes establishing, managing and supporting a source evaluation board in response to the RFP.

4.A.B.3 End Item IPT Support

This element encompasses all the work required to operate an Integrated Product Team (IPT). The IPT is made of cross-functional disciplines grouped to focus on an individual product. IPTs will be chartered to design, develop, and deliver the major assemblies for physical integration into the system of system end item. Each prime contractor will be required to propose an IPT structure for their design (i.e. five digit WBS level and below). Their customer is the SS End Item Program Manager. IDTs provide discipline-specific support to Project Constellation, and the development programs within the IPT team structure, with an independent reporting path through Project Constellation's System Engineering & Integration (SE&I) Office. The teams are staffed with joint membership including prime contractors and independent experts (government civil service, support contractor, and FFRDC) and are distributed "in the field" to provide a mechanism for organizing center support to Constellation programs.

4.A.B.3.1 Systems Engineering & Integration IPT Support

This element describes the work associated with design, development and delivery of products in support of an end item delivery. These system engineering and integration

efforts are two fold. First, is to develop and provide systems engineering products, such as requirements, integrated master schedules, validation/verification plans, etc., in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.2 Constellation Systems Analysis IPT Support

This element describes the work associated with design, development and delivery of products in support of an end item delivery. These system analysis efforts are two fold. First, is to develop and provide systems analyses products, such as analysis models, trade studies, analytical consistency plans and analysis reports in support of the end item program manager's need to validate and verify end item product designs. Second, is to provide a check and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues through analyses.

4.A.B.3.3 Cost Engineering IPT Support

This element describes the work associated with cost modeling, estimating and tracking procurements in support of an end item delivery. These cost engineering efforts are two fold. First, is to develop and provide cost engineering products, such life cycle cost models, budgets and earned value management anlaysis in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.4 Safety & Mission Assurance IPT Support

This element describes the work associated with safety and mission assurance products in support of an end item delivery. These safety and mission assurance efforts are two fold. First, is to develop and provide safety and mission assurance products, such as FEMAs, safety requirements, reliability assurance and quality control in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.5 Operations IPT Support

This element describes the work associated with operations products in support of an end item delivery. These operations engineering efforts are two fold. First, is to develop and provide operation engineering products, such operations concepts, operational scenorios, desigm reference missions, timelines, procedures and operational protocols in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the

discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.6 Human Centered Engineering IPT Support

This element describes the work associated with design, development and delivery of products in support of an end item delivery. These system engineering and integration efforts are two fold. First, is to develop and provide systems engineering products in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.7 Structural, Mechanical, Materials & Manufacturing (SMMM) IPT Support

This element describes the work associated with design, development and delivery of SMMM products in support of an end item delivery. These structural, mechanincal,materials and manufacturing efforts are two fold. First, is to develop and provide SMMM products such as structural design, analysis and testing, loads analysis, manufacturability studies, mass properties management, etc. in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.8 Command, Control & Communications (CCC) IPT Support

This element describes the work associated with design, development and delivery of computer command, control and communications products in support of an end item delivery. These command, control and communication efforts are two fold. First, is to develop and provide CCC products, such as command/communication architectures and protocols, etc. in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.9 Ground Infrastructure IPT Support

This element describes the work associated with design, development and delivery of ground support products in support of an end item delivery. These ground infrastructure discipline efforts are two fold. First, is to develop and ground infrastructure assessment products in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.10 Aerosciences & Flight Mechanics IPT Support

This element describes the work associated with design, development and delivery of aerosciences and flight mechanics products in support of an end item delivery. These aerosciences and flight mechanics efforts are two fold. First, is to develop and provide aeroscience and flight mechanics products such as aerothermal analysis of vehicle aeroshell, trajectory algorithm design and analysis, etc. in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.11 Propulsion & Fluids IPT Support

This element describes the work associated with design, development and delivery of propulsion and fluids management products in support of an end item delivery. These propulsion and fluids discipline efforts are two fold. First, is to develop and provide propulsion and fluids products such as propulsion systems design, analysis and testing, cryogenic fluid management designs and analysis, etc. in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.3.12 Power Systems IPT Support

This element describes the work associated with design, development and delivery of power supply, distribution, and regulation products in support of an end item delivery. These power systems discipline efforts are two fold. First, is to develop and provide power system products, such as photovoltaic energy conversion, batteries, fuel cell, nuclear electric generators, etc. in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues

4.A.B.3.13 Computer, Software, Automation (CSA) IPT Support

This element describes the work associated with design, development and delivery of computer and software products in support of an end item delivery. These computer, software and automation efforts are two fold. First, is to develop and provide systems engineering CSA products in support of the end item program manager's need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues

4.A.B.3.14 Robotics IPT Support

This element describes the work associated with design, development and delivery of products in support of an end item delivery. These system engineering and integration efforts are two fold. First, is to develop and provide systems engineering products in support of the end item program manager need to deliver and end item product. Second, is to provide a checks and balance role to the project through both the manager and the discipline team lead. These checks and balances are to identify, evaluate and mitigate risks, requirements and technology gap issues.

4.A.B.4 End Item Prime Contract

This element encompasses all the work necessary to interface, collect, communicate and negotiate contract needs. This element also encompasses the roll up of the prime contractor earned value management data.

4.A.B.4.1 End Item System Management

This element encompasses all the work required to organize, plan, lead, and control all facets of the activities required by a prime contractor to develop the contract end item systems. This effort includes: leading the overall end item business and administrative management functions, including establishing and maintaining an earned value management (EVM) system for determining budget requirements, conducting analysis, and controlling allocation; all activities associated with developing and executing the acquisition and procurement strategy; workforce requirements and utilization; integrated master plan and schedule (IMP/IMS) development, execution, and assessment; and information management and dissemination. Documentation includes an investment plan based on WBS gap analysis/Industry concept studies.

4.A.B.4.1.1 Business Management

This element encompasses all coordination activities associated with the acquisition strategy, systems authorizations, budget analysis and allocation, system workforce utilization, and integrated program assessment measurement.

4.A.B.4.1.2 Information Management

This element encompasses the effort required to disseminate required information to systems stakeholders. Additionally, this element encompasses the effort required to develop a end item contract communication and reporting plan and respond to unexpected requests for information.

4.A.B.4.1.3 Administrative

This element encompasses the effort required to facilitate the systems management operations, including human resources, staff assignments, and security, etc.

4.A.B.4.1.4 Requirements Management

This task provides support to manage programmatic cost, schedule, and scope trade-offs. Scope includes the assurance of the consistent application of program requirements across the Systems elements.

4.A.B.4.1.5 Acquisition Management

This element encompasses all efforts required to develop an acquisition strategy plan for subcontacts. Additionally, solicitation planning, solicitation development, source selection, contract administration, and contract closeout efforts are included here.

4.A.B.4.1.6 Comprehensive Risk Management

This element encompasses all the effort required to prioritize technical and programmatic risks associated with the systems. Technical risks, including identification, analysis, planning, and costs, are recommended by the systems engineering team. Work includes approval and funding of risk mitigation plans, tracking of mitigation progress, and status reporting to system stakeholders.

4.A.B.4.1.7 Supportability and Integrated Logistics Support Management

This element encompasses all efforts for engineering and support considerations necessary to ensure the effective, sustainable, and economical support of a system for its total life cycle. It is an integral part of all other aspects of system acquisition and operation. Work includes development of supportability strategy and establishing and leading a management team with representation from system integrated logistics support activities.

4.A.B.4.2 Systems Engineering

This element includes the implementation of processes necessary to decompose the system element into manageable work elements with focused, prioritized requirements based on a common operational concept, and to allow those decomposed work elements to be readily integrated into the final product that meets its intended capability.

Scope includes the work to ensure that the proper tools, procedures, and processes are applied across all the lower-tier WBS elements with this System. These processes describe the work for requirements formulation, decomposition and prioritization, configuration and data management, risk assessment, system definition, system integration, integrated logistics support, and integrated operations. The requirements include both technical requirements along with the funding and schedule requirements needed to enable these technical requirements. The effort also includes decomposition of requirements to technologies that must be matured prior to system acquisition. Scope includes the systems engineering to support spiral, modular transformation with development in stages (spirals) with evolving modular components and technology maturation for inclusion in future spirals. This includes performing operations studies and analyses, producing operations metrics across system elements, developing operations

life cycle cost assessments, and developing, integrating, and assessing integrated operations schedules.

4.A.B.4.2.1 Engineering Management

The scope of this element includes: the work required to provide full life cycle technical program management for the System element architecture, definition, and engineering functions; leadership of this System element's engineering team; establishment of the standards and specifications that apply to this System and all lower-tier work in compliance with a higher tier; management of the System's action-item list; provision of a technical management liaison to internal and external customers of the System; the resolution of technical issues in this element; and provision of management authority for resolution of lower-tier element technical issues. Scope also includes the work to ensure management rigor focused on scheduled priorities, technical performance, and cost performance in this System element. Scope encompasses the work necessary for organizational implementation for this System's Integrated Discipline Teams (IDT) (defining how IDTs will be set up, executed, and dissolved) in coordination with the System of System's IDT work, the development of this System Element's Integrated Management (or Master) Plan (IMP) and Integrated Master Schedule (IMS) (identifies key events, milestones, reviews, all integrated technical tasks, and risk reduction activities), along with other progress measurement tools to track major reviews progress, programmatic technical performance, develop lessons learned, and the recording of accomplishments. It includes the work associated with reduction in total ownership cost planning and support (cost control, cost reduction, invest to modernize planning, and assurance that life cycle costs are implemented as co-equal to performance in acquisition). Scope also includes the work to exercise final authority over all lower-tier studies and other decisions. Documentation products include, but are not limited to, a Systems Engineering Management Plan (SEMP), Integrated Discipline Team Manual, a System Element Architecture Roadmap, project technical review plans, and systems engineering management reports.

4.A.B.4.2.2 Requirements Definition

This element provides for an analysis of mission needs, operations concept, System requirements, and the documentation of the resultant requirements. It comprises the work required for requirements analysis, including trade studies and documenting requirements specifications. It includes the work required for the successive refinement of decomposition (partitioning) of system requirements into allocated and derived requirements, appropriately assigned to lower-level products. Scope includes the work to document verification and compliance requirements at the level. Scope includes the derivation and tracking of key performance parameters and operational thresholds and objectives. Scope also includes: the work required for the definition, execution, and documentation of trade studies for desired and practical trade-offs among stated requirements (user requirements, design, program schedule, and functional, performance, and life-cycle costs); trades at various levels of functional or physical detail to support requirements, functional decomposition/allocation, and design alternative decisions, or as specifically designed, to support the decision needs of the systems engineering process; and the work required to integrate all requirements, such that all requirements

decompose down and integrate up to provide total traceability and includes the work to ensure that the final architecture meets interface requirements and is balanced (performance balanced with cost, schedule, and effectiveness requirements). This element also contains the work to support an assessment of design-related changes in requirements for System capabilities. The assessment involves near-term increment requirements to be formulated in an interactive manner to the System definition (design) effort until the Preliminary Design Review (PDR) milestone. Generally speaking, the requirements development effort for that particular increment is complete after PDR and requirements resulting after PDR are deferred to future increments for the particular system. Additional scope includes the work to capture decision-database information for decision rationale traceability and documentation products including, but not limited to: a refined System Requirements Document (SRD) (that contains performance, operational, functional, evaluation criteria, interface, and associated environmental requirements); a refined Concept of Operations for the architecture; and an Interface Requirements Document for this .

4.A.B.4.2.3 Configuration and Data Management

This element captures the efforts for managing the overall configuration of the system flight and ground systems throughout the development, implementation, and operations in compliance with higher-tier configuration and data management policy. Scope involves the planning, organization, integration, support, and monitoring functions for tracking changes, conducting change board reviews, and maintaining configuration documentation to include decision support data. This element includes management of document configuration at the system level and establishes policy and standards for the system level configuration management activities. Scope includes an interface to the System of Systems configuration and data management.

4.A.B.4.2.4 Risk Identification and Analysis

This element includes the overarching identification and analysis for risk reduction at the system level in compliance with the SS Risk Management system. These processes shall be applied to the technical, schedule, and cost aspects of the system. It includes oversight and insight in the planning and conducting of project/demonstrations for the identification of risk, and trade analysis to reduce the risk of the overall program, as well as this WBS element. Additionally, this element includes training in, and execution of, specialized risk identification techniques that are performed on an as-needed basis for activities under this Constellation system. Also includes identification of risk mitigation task requirements, resources, and schedule and reporting to higher tier management.

4.A.B.4.2.5 System Definition

This element includes the work to oversee the design of the systems that comprise the System element and ensures that physical and functional interfaces are maintained between physical products and functional processes. This element contains the work to monitor lower-tier design activities and guides the implementation of procedures necessary to concurrently develop products and their associated processes. Work includes participation in design reviews to represent the integrated vision for functional, physical,

and operational considerations in lower-tier product design and associated manufacturing, test, and support processes that meet the intended need. System analyses include operational feasibility studies, effectiveness analyses, environmental assessments, long-term logistics support assessments, technology assessments, industrial base assessments, and life cycle hardware and software feasibility assessments based on design models and resultant overall systems risk identification. Scope includes continual iteration of increasing-detailed analyses as the system progresses through its life cycle to support sound decisions and to ensure safety, readiness, and continual reductions in the cost of operations. Scope includes the work to capture decision-database information for decision rationale traceability. Documentation products include, but are not limited to: a System Design Document that contains an operational, physical, and functional concept for the architecture (describes the physical, operational and functional view of the system); Design Reference Mission Profile; Natural Environments Definition for Design Document; System Design Documentation (drawings and associated build-to documentation, development specifications, software development folders, material specifications, etc); Interface Control Document; requirements traceability matrix; system concept documentation; trade study reports; discipline analysis reports; Final Environmental Impact Statement; As-Designed EEE Parts List; Command and Data Management functional descriptions, discipline plans and reports (e.g., Fracture Control Plan, EEE Nonstandard Parts approval list, EEE Parts Control Plan, etc.); System Connectivity Diagrams and End-to-End Functional Schematics; Critical Items List; Mass Property Control Report; Radio Frequency Communications Systems Analysis and Studies; Interoperability Plan; and Human Rating Plan, etc.

4.A.B.4.2.6 System Integration

This element contains the work necessary to oversee the lower-tier systems development and ensure compliance in their technical documentation of the system's technical characteristics, including: interface control documents; lower-tier development progress reports and analyses; lower-tier systems verification requirements and plans; and integration of the system elements into the operational scenario. This element encompasses the effort required to plan, monitor, and certify the verification, validation and acceptance of the System element to ensure that it meets the requirements and can execute the mission objectives as intended. Scope involves assurance that all supporting system elements are ready to support end-to-end tests, definition of key system test plans for completeness and ability to meet goals, and review of key test scripts for timing and order of execution of command sequences. The validation, verification, and acceptance work is planned for each level of the system as it is reintegrated in design from the bottoms up (the right half of the systems engineering "vee"). This work includes verification that the requirements (for the entire life cycle) are met, interface requirements are met and controlled, interoperability requirements are addressed, and each requirement has a corresponding completed verification item via the methods identified to perform the verification according to the test plans used to conduct the VV&A. Scope includes the work to support the development of this System's Test and Evaluation Master Plan (TEMP), and the Operational Test and Evaluation Plan.

4.A.B.4.2.7 Integrated Logistics Support

A composite effort of all the engineering, supportability analysis, planning, and support considerations necessary to assure the effective, sustainable, and economical support of the system for its life cycle. It is an integral part of all other aspects of system acquisition and operation. It also provides oversight and insight to the system and components. Deliverables include an initial Integrated Logistics Support Program Plan (ILSPP) that will include the System Supportability Strategy and will address the factors of ILS to be considered early in system design continuing through operations support and disposal.

4.A.B.4.3 Safety and Mission Assurance

This end item system project element includes the technical and management efforts for developing and implementing requirements for the safety and mission assurance (S&MA) function in the disciplines of safety, environmental protection, reliability, maintainability, supportability assurance, quality assurance, and operations. This effort also includes an independent review and assurance function over the design, development, review, and verification of the system and its components. This element covers the areas of Management and Administration along with Business Management for this Constellation element system.

4.A.B.4.3.1 Management and Administration

This WBS element includes the work to lead and manage the safety and mission assurance effort and provide the primary safety and mission assurance interface to the government manager. Includes support of necessary agreements (Annual Operating Agreement (AOA), Memorandum of Agreement (MOA)), resource plans (Program Operating Plan (POP)), schedules, and procedures to guide and direct the mission assurance functions through all phases of the initiative, from design through disposal. This effort provides sufficient review for certification of flight worthiness. Management and Administration will act as a liaison between organizations and between contractors and organizations to provide smooth communications and to facilitate distribution and review of deliverables, and to coordinate exchange of information. This effort will: schedule or participate in scheduling of major reviews, programmatic meetings, presentation of analytical results and other such meetings as directly affect the system; and coordinate and facilitate safety and mission assurance meetings/conferences to cover all aspects of safety, mission assurance, and risk to the project.

4.A.B.4.3.1.1 Business Management

This element encompasses all coordination activities associated with the acquisition strategy, systems authorizations, budget analysis and allocation, system workforce utilization, and integrated program assessment measurement. Includes review and provides support and budget for Annual Operating Agreement and Memorandum Of Agreement. It provides metrics to demonstrate status and progress.

4.A.B.4.3.2 Safety and Mission Assurance Integration

This element includes the technical and management efforts necessary for establishing and integrating S&MA functions in this end item system. Includes development of necessary plans; establishment of adequate safety, maintainability, and reliability design requirements; and procedures to guide and direct the integrated S&MA functions through all phases of the initiative, from design through disposal. This element ensures continuity across all lower-tier S&MA (Safety and Mission Assurance) functions. This element also includes planning of the S&MA tasks, along with developing and assessing requirements for a stated system. This element covers the areas of External Assessment along with S&MA for this End item system. This element also includes providing Hazard Analysis, Risk Assessment, Failure Mode Assessments, and other analytical investigations of safety, mission assurance, and quality, or reviews of analysis provided by the contractor(s). This element will participate as appropriate in flight readiness reviews and support the COFR process.

4.A.B.4.3.2.1 External Assessment

This element includes review, consideration, and communication of Independent Assessments for this End item system. Groups that provide independent oversight and technical support, such as the Aerospace Safety Advisory, Independent Program Assessment Office, etc., will be supported in their efforts and their reports will be given full consideration. Independent technical authority will be encouraged and fully supported.

4.A.B.4.3.3 Safety and Mission Assurance Panels

This element includes the technical and management efforts necessary for the operation of Programmatic S&MA Panels. Personnel and technical expertise will be provided to all S&MA board, committees and panels. These supporting functions will be coordinated and facilitated by this element. Such boards include but are not limited to panels such as: the Safety Review Panel (SRP), the Reliability, Maintainability and Supportability (RMS) Review Panel, and the Ground Safety Review Panel.

4.A.B.4.3.3.1 RMS Review Panel

This element includes the technical and management effort necessary to ensure the overall safety and protection of flight and ground personnel, general public, flight/ground hardware, software and facilities through all phases of the initiative, including over(in)sight of contracted efforts. It includes the implementation of requirements for and ensuring the adequacy of: safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of flight/ground hardware and software element, and operations plans and range safety. Also includes the coordination of government contractor safety teams. Element includes development of system level hazard analysis guidelines and integrated hazard analyses (HAs). This element also includes implementation of requirements for each mission dictating safe handling and usage of radioactive elements (where applicable). Human factor strategy for safety of flight and ground personnel will be developed and refined into guidelines.

4.A.B.4.3.4 Safety, Health and Environment Assurance (SHEA)

This element includes the efforts necessary for providing occupational (industrial) safety and health and environmental assurance function for all aspects of this End item system element. This effort includes providing for regulatory assurance function related to Occupational (Industrial) Safety and Health and Environmental Protection on Earth. Specific components of this element which will be considered and planned for include human factors of occupational safety. This element also will: include development and review of guidelines to be established to ensure that the public, ground and flight crews are as safe as possible in executing their duties and assignments; ensure that toxicity, fire, explosion and propellant safety have all been considered and plans are in place to keep the risk at minimum; develop proper techniques for dealing with hazardous or emergency situations such as fire, explosion or propellant mishaps; develop a system, in accordance with Agency guidelines, for properly reporting and investigating mishaps of any nature involving the initiative; develop trending and metrics for mishaps to be able to track and develop corrective action strategies; develop proper emergency response plans and teams to deal with mishaps and emergencies, whether personnel or equipment; establish a plan for steps to deal with contingencies and proper implementation of plans; promote general safety awareness among all employees; develop programs to make employees more aware of safety hazards in the work area; ensure proper certification and instruction for employees who use specialized or hazardous equipment or procedures, such as lifting, laser operation, and radiation safety; and evaluate vulnerability assessment and trending for status and for contingency response planning. This element also includes activities to ensure that this End item element system is compliant with NEPA.

Promote general safety awareness among all employees. Develop programs to make employees more aware of safety hazards in the work area. Ensure proper certification and instruction for employees who use specialized or hazardous equipment or procedures, such as lifting, laser operation, and radiation safety. Evaluate vulnerability assessment and trending for status and for contingency response planning.

4.A.B.4.3.4.1 Occupational (Industrial) Safety

Element includes insight function necessary for assuring a system complies with federal or state Occupational Safety regulations.

4.A.B.4.3.4.2 Occupational Health

Element includes insight function necessary for assuring a system complies with federal or state Occupational Health regulations.

4.A.B.4.3.4.3 Environmental Protection

Element includes insight function necessary for assuring System elements across System programs comply with federal or state environmental regulations. This element also includes the development of plans and requirements to ensure that all System element SSs are compliant with the NEPA.

4.A.B.4.3.5 Reliability and Maintainability

This element includes the technical and management efforts necessary for assuring reliability, maintainability and supportability for all aspects of the initiative. Establish methods and guidelines for determining hardware reliability using some combination of analysis, test, demonstration, or similarity. Consider and plan for human reliability in all aspects of their function. Establish backup plans for the failure of the human element. Ensure a maintenance concept is supportive of the Mission Concept of Operations. Ensure logistics elements responsible for the Integrated Logistics Support Plan include integration of reliability and maintainability elements.

4.A.B.4.3.5.1 Reliability

This element includes the tasks necessary to ensure the overall reliability of this End item system element. This element will implement requirements for, and ensure adequacy of, reliability analyses, reliability/risk assessments/tradeoffs, coordination between government and contractor reliability teams, and requirements compliance. Element includes development and maintenance of Integrated End item Reliability documents, including Integrated Reliability Policy; Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL) Guideline; Probabilistic Risk Assessment (PRA) guideline and analysis; Problem Reporting and Corrective Actions (PRACA) Guideline; and Integrated FMEA/CIL Design Verification. This element will also: develop a strategy for gathering and using trending analysis in reliability consideration; factor reliability into all aspects of hardware limits and life, such as, but not limited to, FEMA/CIL and Limited Life Requirements and Tracking; establish Problem Reporting and Corrective Action system for this End item system element; and recommend design changes to improve hardware/software reliability.

4.A.B.4.3.5.2 Maintainability

This element includes the review/performance of those tasks necessary to ensure the overall maintainability of this End item system element consistent with the Mission Concept of Operations. Implement requirements for and ensure adequacy of maintainability analyses, maintenance/replacement tradeoffs, coordination between government and contractor maintainability teams, and requirements compliance. This element includes development and maintenance of the Integrated End item Maintainability assurance documents, including Integrated End item Maintainability Policy; Maintenance Concept; Maintainability Program Plan; and Maintainability Design Criteria Document. This element also includes maintainability demonstrations, ensuring that a maintenance data collection system is established to allow trending analysis and consideration of limited life items, their disposition and effect on program. These elements also will recommend design changes to improve hardware/software maintainability.

4.A.B.4.3.6 Product Assurance

This element includes the technical and management efforts necessary for ensuring establishment, management, and maintenance of the overall quality system for this End

item system element hardware and software. This element will implement requirements for, and ensure adequacy of: product assurance requirements/plans; performing inspections and audits; monitoring quality; and maintaining oversight of the procurement, design review, manufacturing, testing/verification, and validation efforts, including provisions for insight/oversight of contracted efforts for all aspects of this End item system element; ensure adequacy and implementation of product assurance requirements/plans; performing inspections and audits; monitoring quality; and maintaining oversight of the procurement, design review, manufacturing, testing/verification, shipping and delivery and validation efforts, including provisions for insight/oversight of contracted efforts for all aspects of this End item system element; establish strategy for how to enfold into the assurance models such things as hardware and software certification, verification, validation, qualification, and Acceptance Data Package; establish a risk management plan, to include PRACA, trend analysis and Government-Industry Data Exchange Program (GIDEP) data; and assist in formulating an acquisition strategy that incorporates aspects of product assurance. Additionally, this element covers the area Electrical, Electronic, Electromechanical (EEE) Parts for this End item system element.

4.A.B.4.3.6.1 Electrical, Electronic, Electromechanical (EEE) Parts

The technical and management efforts necessary for ensuring the establishment, management, and maintenance of parts control programs for this End item system element. This element will ensure adequacy and implementation of the: establishment and maintenance of parts lists; review and issuance of alerts/advisories; parts control; part test/qualification/screening programs; parts testing activities; and test reporting, including provisions for insight/oversight of contracted efforts for all aspects of the initiative. This element includes development and maintenance of this End item system element EEE Parts Program Plan.

4.A.B.4.3.6.2 Materials and Processes Product Assurance

This element includes the technical and management efforts necessary for ensuring the establishment, management, and maintenance of processes for materials and processes assurance/certification for this End item system. This element is to ensure that Material(s) Identification and Usage Lists (MIUL), and Material(s) Usage Agreements (MUA) are done properly and adequately reviewed and approved for this End item system element.

4.A.B.4.3.7 Software Assurance

This element includes the effort necessary to ensure that developed software meets overall S&MA requirements for the protection of flight and ground personnel, general public, flight/ground hardware, software, and facilities through all phases of the initiative, including insight/oversight of contracted efforts. This element will ensure adequacy and implementation of software safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of flight/ground software element and operations plans and range safety. Includes development and maintenance of the this End item system element Software Quality Plan

This element is responsible for: the technical and management efforts necessary for ensuring that mission requirements and system design changes are carried forward across software life cycle phases of this End item system element; the management and technical interfaces, provision of products and artifacts, and responses to issues necessary to support Independent Verification and Validation (IV&V) throughout the life cycle; and establishing requirements of certifying software, performing trending analysis, and establishing reliability and tracking quality that will be used in demonstrating software assurance.

4.A.B.4.3.8 Operations Safety and Mission Assurance

This element includes the technical and management efforts necessary for ensuring performance of ground operations processes and procedures. This element will also ensure adequacy and implementation of operational procedures, checklists, and guidelines, including pre- and post-operation checkout with respect to known hazards and system failure modes. Participation in operations includes the assessment of changes to procedures, etc., for the purpose of maintaining the validity of hazard and failure controls. This element also provides monitoring of real time ground operations. Establish plans for contingencies. Ensure adequate policy for ground operations. Ensure proper range safety procedures and policies are implemented.

4.A.B.4.3.9 Human Rating and Crew Survival

This element provides for the effort necessary to certify human–rated space flight systems and to ensure the use of all available mechanisms including abort and escape, safe haven, emergency egress, and search and rescue for human space flight systems. It also determines if the program has implemented all design efforts established, assessed, and documented agency requirements for an acceptable life cycle cumulative probability of safe Crew and passenger return for all missions over the life of all System programs and projects. The element also determines if that all human–rated flight systems are designed in compliance to agency Human-Rating Requirements for Space Flight Systems to preclude a catastrophic safety risk to the flight Crew**.**

Establish human performance criteria and system usability requirements to ensure crew safety. Certify space flight systems reliability and safety by test and analysis at the integrated system level prior to the first flight with humans on board. Develop and implement a formal process to maintain the human-rating certification for the life of the program. Complete structured usability testing with crew involvement to verify that the system design meets the required human performance criteria during system operation, maintenance, and control. Test, verify and validate the performance, security, and reliability of all critical software across the entire flight envelope, as well as mission functions, modes and transitions. Develop and utilize a testing facility with a flight-equivalent avionics test-bed operating in a real-time, closed-loop test environment. Test ground software on the computer platforms that will be used to support flights. Confirm the integrity of the software design and testing process through independent verification and validation methods. Critical software is any software component whose failure or unanticipated performance could lead to the loss of the space flight system or crew and

passengers. This includes the flight software as well as ground software that can affect flight safety.

4.A.B.4.3.10 Nuclear Safety

This element includes the effort necessary to ensure the overall safety and protection of flight and ground personnel, the general public, flight/ground hardware, software, and facilities through all phases of the initiative when nuclear material is present. This element will include a nuclear risk management evaluation. This element will also ensure adequacy and implementation of safety plans, hazards analyses, safety non-compliance disposition, and safety assessment, reports, and reviews of nuclear hardware elements and operations plans and compliance with Federal law and regulations. This also includes support to the Inter-agency Nuclear Safety Review Panel (INSRP). This element will also implement policy prescribed in the National Environmental Protection Act (NEPA.

4.A.B.4.4 Reserved

4.A.B.4.5 Integration and Test

This element encompasses hardware related activities associated with integration of the spacecraft. It includes analysis and design at the spacecraft level, testing at the same level, and final assembly/checkout. Hardware/software integration is likewise included. The lower level structure subordinate to this item may be program peculiar, but must account for each item decomposed below.

4.A.B.4.5.1 Vehicle Level Analysis and Design

This element encompasses all the work required for integrated vehicle design, analysis, and modeling; acquisition, mass properties analysis; loads and dynamics analysis; thermal analysis; flight mechanics and performance analysis; and contamination analysis.

4.A.B.4.5.2 Vehicle Level Test

This element encompasses hardware related activities associated with mockups, vehicle level test hardware, vehicle level development/qualification test operations, vehicle level acceptance test operations. And module level test if applicable.

4.A.B.4.5.3 Final Assembly

This element encompasses all the work required for equipment installation and alignment; major segment mating, and module packaging, if applicable.

4.A.B.4.6 Integrated Operations

This element focuses on the integration of the System operations and provides the planning, directing, controlling, and execution of an integrated operations effort to meet System mission objectives. This element encompasses operations integration activities, integrated logistics support, and consolidated operations implementation to support an integrated System mission and provides insight into operations common or multi-use systems to provide a balanced and integrated operation capability. This effort also

includes integration of NASA's operational expertise in the design and development of System focusing the expertise on each system and horizontally across the program to ensure integrated operations capability across the system. The Integrated Operations activity also includes assessing the schedule and cost control for operation and sustainment of the mission operations activities throughout the system life cycle and producing operations metrics to ensure the most efficient and effective operations throughout the life of the system

4.A.B.4.6.1 Operations Management

This element encompasses all the work required to manage and administer all facets of the operations activities at the System level. It leads the operations team in the early planning of mission operations, integrated support to designing the mission operations system and conducting of System mission operations. Also includes System operations document and processes development (operations implementation plan, mission planning and manifesting processes, etc). It addresses the work necessary to support the Integrated Management (or Master) Plan (IMP) and Integrated Master Schedule (IMS) (identifies key events, milestones, reviews, and all integrated operations tasks) along with other progress measurement tools to track operations performance.

4.A.B.4.6.2 Operations Integration

This area performs operations integration across the enterprise system by translating System mission objectives and requirements into a viable mission operations concept. During the development of the operations infrastructure, this area integrates the System mission and operations planning, processes, tools, facilities and systems to promote and ensure consistency, compatibility, and efficiency across the System. This element will focus on the following:

1. Integration of the system of system operations, and provide balanced and integrated Operations Products to the Program
2. Integrate NASA's Operational expertise in the design and development of the System, focusing the expertise on each system and horizontally across the program
3. Ensure integrated operations capability across the system
4. Assess the schedule and cost control for the development and operation of the mission operations activities throughout the system life cycle
5. Manage the operations metrics to ensure the most cost efficient operations throughout the life of the system

4.A.B.4.6.2.1 Ground Operations Integration

This element captures the overall ground processing integration and coordination across the elements to ensure commonality and standardization for the System missions. This includes defining, and developing the integrated plans and processes for ground processing activities. Ground Processing includes the activities required to prepare a mission for flight (i.e. vehicle processing; maintenance and refurbishment; assembly, test, and check-out; integrated testing, launch operations; and recovery operations). This

element also captures the coordination of launch site processing ground systems including facilities, support equipment, and check-out equipment. Includes support of systems engineering efforts that define and document the ground, launch, and range operations requirements; plans, procedures, and tools to satisfy requirements; and training, test, and certification plans.

4.A.B.4.6.2.2 Mission Operations Integration

This element provides mission operations integration and coordination across the elements to ensure commonality and standardization for the System missions. This includes defining and developing the integrated plans and processes for flight operations activities. Mission Operations includes the activities required to prepare a mission for flight (i.e. plans, procedures, tools, flight design, and training, test, and certification plans). This activity also supports the coordination of flight operations communication, commanding, controlling, data analysis, and anomaly resolution and contingency planning capabilities. Includes support of systems engineering efforts that define and document the mission operations requirements; plans, procedures, and tools to satisfy requirements; and training, test, and certification plans.

4.A.B.4.6.2.3 Surface Operations Integration

This element captures the overall surface operations integration and coordination across the System to ensure commonality and standardization. Surface operations includes the activities performed on the lunar and planetary surface including system and science operations, servicing, maintenance, repair, handling, surface preparations, and environmental issues (e.g. electrostatic properties of dust).

4.A.B.4.6.3 Consolidated Systems Operations

This element captures the integration effort required when two or more systems or their respective elements (CEV, transfer stage, lander, habitat, etc) are supporting a System mission during the planning and execution phase of operations. The activities to be included in this element are mission integration, ground processing, mission operations, and lunar/planetary surface operations. For example the flight planning activities for an on-orbit rendezvous of two space vehicles would be included as a part of this work as well as subsequent execution of the flight operations to support this task. Common and multi-use facilities operations and maintenance activities will be captured in 4.7 and unique element operations will be defined for each element in WBS elements 4.8-4.12.

4.A.B.4.6.3.1 Mission Integration

This element provides the analysis and integration of ground, flight and surface operations planning, preparation and execution for the System through all phases of operations, including the necessary ground facilities, equipment, systems and software. This element ensures that the enterprise mission and operations planning, processes, tools, facilities and systems are implemented efficiently across the enterprise. This element implements the environmental compliance initiatives for ground, flight, and surface operations. Also, included in this element are the definition, preparation, and conduct of mission readiness reviews

4.A.B.4.6.3.2 Ground Processing

This element captures the integrated ground processing operations activities for the System missions. This includes but is not limited to; certification, training, simulation, ground processing operations, and support and disposal through the System life cycle.

4.A.B.4.6.3.2.1 Certification

Ground system validation tests to demonstrate capability and readiness to launch System Missions. Includes certification of facilities, support equipment, and personnel, Prepare test plans and provide test reports.

4.A.B.4.6.3.2.2 Training and Simulation

The work associated with training and certification of ground operations personnel for Exploration Missions. This includes lesson and training material development, software, and simulated flight element hardware, facilities, conduct of training, launch rehearsals, tests and maintenance of test results. Tasks also include preparing plans and producing training reports. Training work occurs both prior to and during ground processing operations.

4.A.B.4.6.3.2.3 Logistics

This element captures the integrated operations logistics activities for the System ground processing operations. Activities included in this element are logistics management and integration, logistics engineering, maintenance and supply support, parts sparing (including flight hardware), government property management, and government furnished services.

4.A.B.4.6.3.2.4 Launch Preparation Operations

The technical and management efforts to direct and control the integrated ground operations activity in preparation for and execution of launch site operations in support of System Missions. This includes execution of the activities to prepare the flight hardware for launch, including but not limited to, flight hardware receIDT and inspection, maintenance and refurbishment, assembly and checkout, integrated testing, hardware servicing, integration with the launch vehicle, payload processing and integration, and transportation.

4.A.B.4.6.3.2.5 Launch Operations

The technical and management efforts to direct and control the integrated ground operations activity in preparation for and execution of launch of System Missions. This includes, but is not limited to, final preparations for launch and launch countdown activities.

4.A.B.4.6.3.2.6 Landing and Recovery Operations

The technical and management efforts to direct and control the integrated landing and recovery operations activities in preparation for and execution of landing and recovery of

System Missions. This includes, but is not limited to, recovery and safing of the flight hardware after a mission and transportation to a post-flight processing facility.

4.A.B.4.6.3.2.7 Launch Abort and Recovery

The technical and management efforts to direct and control the ground operations activity in preparation for and execution of launch aborts and recovery in support of System Mission components. This includes, but is not limited to, recovery and safing of the flight hardware after a mission and transportation to a post-flight processing facility

4.A.B.4.6.3.2.8 Range Operations

The technical and management efforts to direct and control the range operations activities in preparation of and execution of range operation in support of System Missions. This includes, but is not limited to, supporting hazardous activities at the launch site, launch operations, and landing and recovery operations. This element also includes scheduling the range support in support of Exploration Mission activities.

4.A.B.4.6.3.2.9 Retirement/Disposal

The activity associated with planning for and executing the disintegration of the ground processing operations complex and disposal of the associated assets consistent with ITAR and NEPA restrictions.

4.A.B.4.6.3.3 Mission Operations

carry out the integrated mission objectives. To accomplish the mission, several launches may be required to place the Systems in space. The pre-flight planning phase includes the mission planning of events and basic crew/flight control team timelines associated with each flight; the flight dynamics design; the crew and flight control team training; development and verification of the flight procedures (nominal and malfunction recovery), flight rules, system schematic, systems supporting documents (systems briefs), command and control tools, and data display and analysis tools. With the pre-mission preparation complete, the flight crew and flight control team are ready to proceed to flight operations execution and accomplish the mission objectives.

4.A.B.4.6.3.3.1 Certification

Prepare, coordinate, and conduct integrated mission operations system validation tests to demonstrate the capability and readiness of the mission operations system to operate and support the System missions. Provide the mission operations V&V system engineer a process which assures the integrated mission operations system is ready and capable of safely carrying out its intended purpose. Prepare the test plan and provide test reports.

4.A.B.4.6.3.3.2 Training and Simulation

This element provides resources to perform integrated training and certification of crew and operations personnel for the System Missions. This includes lesson and training material development, mock-ups, trainers, simulators, facilities, and supporting software; preparation, planning, and coordination for incorporation of the trainers into the training

flow; conduct of operations training, rehearsals, and tests. Tasks also include preparing the operations training plan and producing training reports. Training will occur both prior to and during flight operations

4.A.B.4.6.3.3.3 Logistics

This element captures the integrated operations logistics activities for the System mission operations. Activities included in this element are logistics management and integration, logistics engineering, maintenance and supply support, parts sparing (including flight hardware), government property management, and government furnished services.

4.A.B.4.6.3.3.4 Flight Design and Flight Planning

This element provides technical and management resources to perform an integrated mission planning process for the System. This element is an integrated process of the flight design responsibilities and the flight plan development. The Flight Design portion includes analysis of launch opportunities, ascent, orbit, rendezvous, and entry / landing in preparation for the execution of a mission. A mission may include multiple launches of crewed and un-crewed elements. The Flight Planning portion of the element includes the integrating and coordinating high-level requirements, tasks, science objectives, ground commanded activities, attitude and pointing requirements, and crew constraints into a cohesive, integrated plan. The task will result in the preparation and publishing of an integrated flight plan. Flight planning will occur both prior to (pre-flight) and during flight operations (re- planning).

4.A.B.4.6.3.3.5 Payload Planning

This element provides resources to perform payload planning for the System missions. This includes integrating and coordinating high-level payload requirements, tasks, payload science objectives, payload ground commanded activities, payload attitude and pointing requirements, coordinating activities with Primary Investigators, and providing payload inputs into the crew activity scheduling. Task also includes preparing and publishing various operations integration documents. Payload planning will occur both prior to (pre-flight) and during flight operations (re- planning).

4.A.B.4.6.3.3.6 Flight Operations Products and Procedures Development

This element includes all documentation necessary for capturing the operations knowledge of the spacecraft associated with the System integrated missions' activities. These documents include flight rules, nominal and off-nominal (malfunction) response procedures for the flight crew and flight controllers, operations related drawings, spacecraft system briefs, and console operations briefs. This element also includes the software tools and supporting documentation used by the flight control team in their pre-flight assessments for power, life support, thermal, and propulsion. Additional software tools and supporting documentation are developed for ground commanding to the various spacecraft and for supporting spacecraft telemetry display and interpretation applications.

4.A.B.4.6.3.3.7 Flight Operations

The technical and management efforts to direct and control the integrated mission operation activities associated with the executions of System mission operations including all activities associated with the flight crew and flight control team support. It includes the efforts to plan and execute the integrated flight operations requirements; using the plans, procedures, tools and training. This activity supports the flight operations of the System missions with communication, commanding, controlling, data analysis, and anomaly resolution and contingency planning capabilities.

4.A.B.4.6.3.3.8 Retirement Disposal

The activity associated with planning for and executing the disintegration of the mission operations complex and disposal of the associated assets consistent with ITAR and NEPA restrictions.

4.A.B.4.6.3.4 Surface Operations

This element captures the integrated surface operations activities for the System missions. This includes but is not limited to; integrated planning, training, simulation, flight certification, surface system infrastructure and science operations, and support and disposal through the System life cycle.

4.A.B.4.6.3.4.1 Certification

This element provides for the preparation, coordination, and conduct of surface operations integrated system validation tests to demonstrate the capability and readiness of the surface operations system to operate and support the System Missions. Provide the surface operations V&V system engineer a process which assures the surface operations system is ready and capable of safely carrying out its intended purpose. Prepare the test plan and provide test reports.

4.A.B.4.6.3.4.2 Training and Simulation

This element provides resources to perform integrated surface operations training and certification of crew and operations personnel for the System Missions. This includes lesson and training material development, mock-ups, trainers, simulators, facilities, and supporting software; preparation, planning, and coordination for incorporation of the trainers into the training flow; conduct of operations training, rehearsals, and tests. Tasks also include preparing the operations training plan and producing training reports. Training will occur both prior to and during surface operations

4.A.B.4.6.3.4.3 Logistics

This element captures the integrated surface operations logistics activities for the System. Activities included in this element are logistics management and integration, logistics engineering, maintenance and supply support, parts sparing (including flight hardware), government property management, and government furnished services.

4.A.B.4.6.3.4.4 Surface Operations Products and Procedure Development

This element includes all documentation necessary for capturing the operations knowledge of the System elements associated with the System missions. These documents include Flight Rules, nominal and off-nominal (malfunction) response procedures for the flight crew and flight operations team, operations related drawings, and surface operations system briefs. This element also includes the software tools and supporting documentation used by the flight control team in their pre-flight assessments and in-flight verifications for power, life support, thermal, and propulsion margins. Additional software tools and supporting documentation are developed for ground commanding to the various Systems of systems surface elements and for supporting associated telemetry display and data interpretation applications.

4.A.B.4.6.3.4.5 Payload Planning

This element provides resources to perform integrated payload planning for the surface operations of the System missions. This includes integrating and coordinating high-level payload requirements, tasks, payload science objectives, and payload commanded activities, payload pointing requirements, coordinating activities with Primary Investigators, and providing payload inputs into the crew activity scheduling. Task also includes preparing and publishing various operations integration documents. Payload planning for surface operations will occur both prior to (pre-flight) and during surface operations (re- planning).

4.A.B.4.6.3.4.6 Surface Operations

The technical and management efforts to direct and control the integrated surface operation activities associated with the flight crew and flight control team support in their execution of a System mission. It includes the efforts to plan and execute the integrated surface operations requirements using the plans, procedures, tools, and training. This activity supports the surface operations of the System missions with communication, commanding, controlling, data analysis, and anomaly resolution and contingency planning capabilities.

4.A.B.4.6.3.4.7 Retirement Disposal

The activity associated with planning for and executing the disintegration of the mission operations complex and disposal of the associated assets consistent with ITAR and NEPA restrictions.

4.A.B.4.6.3.5 Communications

This element provides resources for all of the integrated network communications for the System mission during test and operations. This includes ground facilities as well as satellite usage.

4.A.B.4.7 Contract End Item Ground Support Systems

This element encompasses the work associated with the acquiring or developing of ground support systems and equipment, which are unique or dedicated to the end item of

which it is subordinate. This section is intended to capture those physical end items necessary to support the space end item being developed. It includes but is not limited to mobile support structures, test fixtures, handling fixtures, computer control and data acquisition ground support equipment and software used during integration, test and checkout of the space end item.

4.A.B.4.8 Contract End Item

This element encompasses the work associated with the acquiring or developing of the space end item architecture derived from allocated requirements. The physical end item is the decomposed product of the system architecture to achieve the required mission objectives.